
SHOUT
SHARE
IT

Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.

BULLETIN OF THE
U.S. DEPARTMENT OF AGRICULTURE

No. 98.

Contribution from the Bureau of Animal Industry, A. D. Melvin, Chief.
August 14, 1914.

(PROFESSIONAL PAPER.)

# THE APPLICATION OF REFRIGERATION TO THE HANDLING OF MILK.

By JOHN T. BOWEN, *Technologist, Dairy Division.*

## INTRODUCTION.

In the following pages an attempt has been made to discuss briefly the various applications of refrigeration, both when employing ice and refrigerating machinery, in the operation of the modern milk plant, creamery, or dairy, and to discuss in each instance the methods most commonly used in the latest and best equipped plants.

While refrigeration has made considerable advancement in dairying in the last few years, even more progress could have been made had more owners and operators of milk plants, creameries, and dairies been fully aware of the many advantages to be derived from the use of proper refrigeration. It is further believed that the manufacturers of refrigerating machinery are not familiar with the special conditions existing in this industry. Therefore the object of this bulletin is to be of service to the manufacturer of refrigerating machinery as well as to those employed in the dairy industry.

It is not intended to give in detail the size and arrangement of refrigerating equipment necessary in plants of various capacities, as the conditions vary to such an extent that to do so would be impossible, but to state briefly the elementary principles of refrigeration and refrigerating machinery and to describe what is recognized as the best and most modern practice in the industry and to leave the details in each case to those on the premises, who are better able to judge and to modify the suggestions given herein to suit the existing conditions.

It is a well-known fact that heat and cold perform very important duties in handling milk and milk products. In pasteurizing milk

NOTE.—Discusses the application of refrigeration in the operation of the modern milk plant and describes the various forms of mechanical and other systems of cooling. Of interest to producers, shippers, dealers, and consumers of milk generally, and also to manufacturers of refrigerating machinery and appliances.

heat is used to destroy the bacteria, or at least to reduce their number to such an extent as to prevent their producing disease; but pasteurized milk as well as unpasteurized market milk should be cooled to a temperature of 50° F. or below and held at this lower temperature until used. At a temperature below 50° F. bacteria multiply less rapidly, but between 50° and 100° F. the increase is very fast; hence the necessity for thorough cooling and the maintenance of low temperatures until used.

## DEFINITIONS OF TERMS.

A knowledge of the terms used in refrigeration is necessary in order to better understand the matter given in the following pages. Therefore definitions of the principal terms and units employed are given for the benefit of those not already familiar with them.

*British thermal unit.*—A British thermal unit (B. T. U.) is the quantity of heat required to raise 1 pound of pure water 1 degree Fahrenheit, at or near its maximum density, 39.1° F. Some authorities consider a British thermal unit as the heat required to raise 1 pound of pure water from 61° to 62° F. For practical purposes, however, it may be considered the heat required to raise the temperature of 1 pound of water 1 degree Fahrenheit.

*Sensible heat.*—Sensible heat is the heat that may be felt by the hand or measured by a thermometer.

*Latent heat.*—Latent or "hidden" heat is the heat which is expended in molecular work of separating the molecules of the substance and can not be measured by a thermometer. Every substance has a *latent heat of fusion,* required to convert it from a solid to a liquid, and another, *latent heat of vaporization,* required to convert it from a liquid to a gas or vapor. Thus, if heat is applied to a pound of ice at 32° F. it will begin to melt, and no matter how much heat is applied the ice will not get any hotter. After every particle of ice has melted, we will have 1 pound of water at 32° F., the same temperature as the ice before heat was applied. Experiments have shown that it requires 144 British thermal units to melt 1 pound of ice at 32° F. into water at 32° F.; hence the *latent heat of fusion* of ice is said to be 144.

If heat is applied to 1 pound of water at 212° F., the water will remain at 212° F. under atmospheric pressure until all of it has been evaporated into steam at 212° F. This has been found to require 970.4 British thermal units; hence the *latent heat of vaporization* of steam at atmospheric pressure is said to be 970.4 B. T. U.

*Specific heat.*—The specific heat of a substance may be defined as the ability of that substance to absorb heat compared to that of water. Water being one of the hardest of all substances to heat, its specific heat is taken at unity. Therefore the specific heat of other substances is usually less than unity. A better understanding of *latent* and *spe-*

*cific heat* may be had by studying the diagram in figure 9, on page 24, which shows graphically the relation of heat to temperature.

*Ton refrigeration.*—Refrigeration, or ice-melting capacity, is a term applied to represent the cold produced, and is measured by the latent heat of fusion of ice, which is 144 B. T. U. per pound. In other words, it is the heat required to melt 1 pound of ice at 32° F. into water at the same temperature. The capacity of a machine in tons of "ice melting" or "refrigeration" does not mean that the machine would make that amount of ice, but that the cold produced is equivalent to the melting of the weight of ice at 32° into water at the same temperature. Therefore 1-ton refrigeration is equal to 144 × 2,000, or 288,000 B. T. U. A 1-ton refrigerating machine is a machine that has a capacity sufficient to extract from an insulated bath of brine 200 B. T. U. per minute, 12,000 B. T. U. per hour, or 288,000 B. T. U. per 24 hours.

*Absolute pressure.*—Absolute pressure is pressure reckoned from a vacuum. Pressure gauges in general use are arranged to indicate pressure in pounds per square inch above atmospheric. To convert gauge pressure to absolute pressure, 14.7 pounds, the weight per square inch of air pressure at sea level, must be added.

## CHANGES IN MILK CAUSED BY TEMPERATURE AND TIME.

### PHYSICAL CHANGES IN MILK AT LOW TEMPERATURES.

During the last decade the progress made in the physical, chemical, and bacteriological studies of milk and its products has greatly modified the various dairy operations and has led to improved methods of treating and handling dairy products, based mainly on the application of the two extremes, heat and cold. The preservation of milk and its products depends almost entirely on the use made of these two factors. In this bulletin, however, we will discuss only the use of refrigeration as a means of preserving dairy products. Before discussing the practical application of refrigeration to the dairy industry it is advisable to make a short summary of the data at hand relating to the physical, chemical, and bacteriological changes and modifications which the action of cold produces in milk.

### SPECIFIC HEAT.

In view of the wide variations in the specific heat of milk and cream, as found in the limited amount of literature on the subject, the United States Bureau of Standards was requested to make determinations of the specific heat of whole milk and single and double cream. Samples of milk and cream, approximating average conditions, were prepared by the Dairy Division laboratories and forwarded to the Bureau of Standards in the afternoon, placed in the calorimeter and packed

in ice until the next morning when observations were begun. The chemical analyses of the samples were as follows: 3½ per cent milk: 12.68 per cent total solids, 9.18 per cent solids not fat, 87.32 per cent water; 20 per cent cream: 27.27 per cent total solids, 7.27 per cent solids not fat, 72.73 per cent water; 40 per cent cream: 44.30 per cent total solids, 4.30 per cent solids not fat, 55.70 per cent water.

In view of the fact that only a single test on one sample of the material was made the results can be considered only as tentative and not final.

TABLE I.—*Specific heat of milk and cream.*

| Temperature. | | Milk. | 20 per cent cream. | 40 per cent cream. | Temperature. | | Milk. | 20 per cent cream. | 40 per cent cream. |
|---|---|---|---|---|---|---|---|---|---|
| °F. | °C. | | | | °F. | °C. | | | |
| 35.6 | 2.0 | ..... | 0.88 | ..... | 95.9 | 35.5 | 0.93 | 0.89 | 0.86 |
| 37.4 | 3.0 | 0.92 | ..... | 0.83 | 100.4 | 38.0 | ..... | ..... | .80 |
| 43.7 | 6.5 | .92 | .91 | .90 | 105.8 | 41.0 | .92 | .87 | ..... |
| 48.2 | 9.0 | ..... | .92 | ..... | 109.4 | 43.0 | ..... | ..... | .78 |
| 51.8 | 11.0 | .93 | ..... | .96 | 114.8 | 46.0 | ..... | .87 | ..... |
| 55.4 | 13.0 | ..... | .94 | ..... | 118.4 | 48.0 | .92 | ..... | .78 |
| 59.0 | 15.0 | .94 | .95 | 1.02 | 123.8 | 51.0 | ..... | .86 | ..... |
| 66.2 | 19.0 | .95 | 1.01 | 1.07 | 127.4 | 53.0 | ..... | ..... | .77 |
| 71.6 | 22.0 | .94 | .95 | ..... | 131.0 | 55.0 | .93 | .86 | ..... |
| 75.2 | 24.0 | ..... | ..... | .93 | 136.4 | 58.0 | ..... | ..... | .76 |
| 78.8 | 26.0 | .93 | ..... | .88 | 141.8 | 61.0 | .93 | .87 | ..... |
| 82.4 | 28.0 | ..... | .91 | ..... | 145.4 | 63.0 | ..... | ..... | .72 |
| 86.0 | 30.0 | .92 | ..... | .88 | 150.8 | 66.0 | .94 | ..... | ..... |
| 89.6 | 32.0 | ..... | .91 | ..... | | | | | |

The curves, figure 1, show the specific heat of 3½ per cent milk and 20 and 40 per cent cream at different temperatures between 35.6° F. and 150.8° F.

## COHESION AND VISCOSITY OF MILK.

Milk upon cooling assumes a denser semiliquid aspect and sticks more closely to the walls of the vessel than when warm. Consequently it is harder to clean, by means of water, a vessel that has contained cold milk than one that has contained warm milk. On the other hand, for the same reason, it is more difficult to cleanse vessels that have contained milk by the use of cold water than by the use of warm water. Milk is more liable to foam when cold than when hot, and the foam will keep longer. The foam, however, will disappear if the milk is heated. With the lowering of the temperature of milk the cohesion increases in proportion to its viscosity.

At 86° F. the viscosity is about 1.7 times as great in milk as it is in water, while at 32° F. its viscosity is about 2.4 times that of water. At 32° F. the viscosity of milk is about 2.6 times as great as it is at 86° F.

Freshly drawn milk shows a smaller viscosity than it does after being allowed to stand for some time. It is a well-known fact that the viscosity plays an important part in the formation of cream and in the skimming of milk.

### COEFFICIENT OF EXPANSION OF MILK AND CREAM.

In Table II is given the change in the volume of milk and cream with varying percentages of fat and degrees of temperature. The

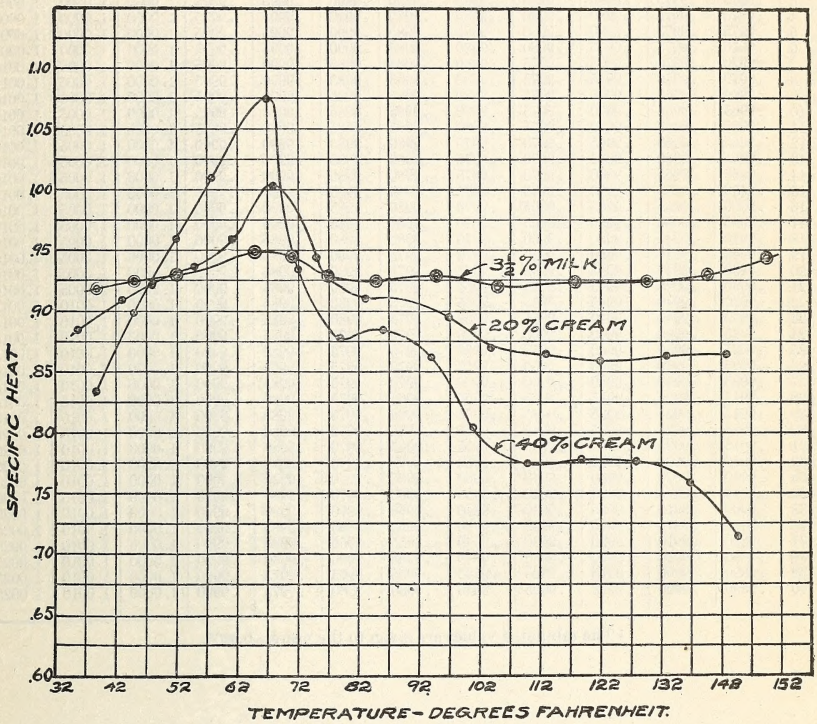



FIG. 1.—Curves showing the specific heat of milk, 20 per cent and 40 per cent cream at different temperatures.

percentage of fat varies in steps of 1 per cent from skimmed milk to double cream, and determination of change in volume has been made in steps of 2° F. from 50 to 140° F. A temperature of 68° F. (20° C.) has been taken as the basis and the change in volume reckoned from this temperature. These tentative determinations and those on specific gravity were made by the Division of Weights and Measures of the United States Bureau of Standards.

TABLE II.—*Volume* [1] *of milk and cream at various temperatures occupied by unit volume at 68° F. (20° C.).*

| Percentage of butterfat. | Temperature (° F.). | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 50 | 52 | 54 | 56 | 58 | 60 | 62 | 64 | 66 | 68 | 70 | 72 |
| | Volume. | | | | | | | | | | | |
| 0.025 | 0.9980 | 0.9980 | 0.9985 | 0.9985 | 0.9990 | 0.9990 | 0.9990 | 0.9995 | 0.9995 | 1.0000 | 1.0000 | 1.0005 |
| 1 | .9980 | .9980 | .9985 | .9985 | .9990 | .9990 | .9990 | .9995 | .9995 | 1.0000 | 1.0000 | 1.0005 |
| 2 | .9975 | .9975 | .9980 | .9980 | .9985 | .9990 | .9990 | .9995 | .9995 | 1.0000 | 1.0000 | 1.0005 |
| 3 | .9975 | .9975 | .9980 | .9980 | .9985 | .9990 | .9990 | .9995 | .9995 | 1.0000 | 1.0000 | 1.0005 |
| 4 | .9975 | .9975 | .9980 | .9980 | .9985 | .9985 | .9990 | .9995 | .9995 | 1.0000 | 1.0000 | 1.0005 |
| 5 | .9975 | .9975 | .9980 | .9980 | .9985 | .9985 | .9990 | .9995 | .9995 | 1.0000 | 1.0000 | 1.0005 |
| 6 | .9970 | .9975 | .9975 | .9980 | .9980 | .9985 | .9990 | .9995 | .9995 | 1.0000 | 1.0000 | 1.0005 |
| 7 | .9970 | .9970 | .9975 | .9975 | .9980 | .9985 | .9985 | .9990 | .9995 | 1.0000 | 1.0000 | 1.0010 |
| 8 | .9970 | .9970 | .9975 | .9975 | .9980 | .9985 | .9985 | .9990 | .9995 | 1.0000 | 1.0005 | 1.0010 |
| 9 | .9965 | .9965 | .9970 | .9975 | .9980 | .9985 | .9985 | .9990 | .9995 | 1.0000 | 1.0005 | 1.0010 |
| 10 | .9965 | .9965 | .9970 | .9975 | .9980 | .9985 | .9985 | .9990 | .9995 | 1.0000 | 1.0005 | 1.0010 |
| 11 | .9965 | .9965 | .9970 | .9975 | .9980 | .9985 | .9985 | .9990 | .9995 | 1.0000 | 1.0005 | 1.0010 |
| 12 | .9955 | .9960 | .9965 | .9970 | .9975 | .9980 | .9985 | .9990 | .9990 | 1.0000 | 1.0005 | 1.0010 |
| 13 | .9955 | .9960 | .9965 | .9970 | .9975 | .9980 | .9985 | .9990 | .9990 | 1.0000 | 1.0005 | 1.0010 |
| 14 | .9950 | .9955 | .9960 | .9970 | .9975 | .9980 | .9985 | .9990 | .9990 | 1.0000 | 1.0005 | 1.0010 |
| 15 | .9950 | .9955 | .9960 | .9970 | .9975 | .9980 | .9985 | .9990 | .9990 | 1.0000 | 1.0005 | 1.0010 |
| 16 | .9950 | .9955 | .9955 | .9965 | .9970 | .9980 | .9985 | .9990 | .9990 | 1.0000 | 1.0005 | 1.0010 |
| 17 | .9945 | .9950 | .9955 | .9965 | .9970 | .9980 | .9985 | .9990 | .9990 | 1.0000 | 1.0005 | 1.0010 |
| 18 | .9940 | .9945 | .9950 | .9960 | .9970 | .9980 | .9980 | .9985 | .9990 | 1.0000 | 1.0005 | 1.0010 |
| 19 | .9940 | .9945 | .9950 | .9960 | .9970 | .9975 | .9980 | .9985 | .9990 | 1.0000 | 1.0005 | 1.0010 |
| 20 | .9930 | .9940 | .9945 | .9955 | .9965 | .9975 | .9980 | .9985 | .9990 | 1.0000 | 1.0005 | 1.0010 |
| 21 | .9930 | .9940 | .9945 | .9955 | .9965 | .9975 | .9980 | .9985 | .9990 | 1.0000 | 1.0005 | 1.0010 |
| 22 | .9930 | .9940 | .9945 | .9955 | .9965 | .9975 | .9980 | .9985 | .9990 | 1.0000 | 1.0010 | 1.0015 |
| 23 | .9930 | .9940 | .9940 | .9955 | .9965 | .9975 | .9980 | .9985 | .9990 | 1.0000 | 1.0010 | 1.0015 |
| 24 | .9925 | .9930 | .9940 | .9950 | .9960 | .9975 | .9975 | .9985 | .9990 | 1.0000 | 1.0010 | 1.0015 |
| 25 | .9925 | .9930 | .9940 | .9950 | .9960 | .9970 | .9975 | .9985 | .9990 | 1.0000 | 1.0010 | 1.0015 |
| 26 | .9925 | .9930 | .9940 | .9950 | .9960 | .9970 | .9975 | .9985 | .9990 | 1.0000 | 1.0010 | 1.0015 |
| 27 | .9925 | .9930 | .9940 | .9950 | .9960 | .9970 | .9975 | .9985 | .9990 | 1.0000 | 1.0010 | 1.0015 |
| 28 | .9915 | .9925 | .9935 | .9945 | .9955 | .9965 | .9975 | .9980 | .9990 | 1.0000 | 1.0010 | 1.0015 |
| 29 | .9915 | .9925 | .9935 | .9945 | .9955 | .9965 | .9975 | .9980 | .9990 | 1.0000 | 1.0010 | 1.0015 |
| 30 | .9915 | .9925 | .9935 | .9945 | .9955 | .9965 | .9970 | .9980 | .9990 | 1.0000 | 1.0010 | 1.0020 |
| 31 | .9915 | .9925 | .9935 | .9945 | .9955 | .9965 | .9970 | .9980 | .9990 | 1.0000 | 1.0010 | 1.0020 |
| 32 | .9910 | .9920 | .9930 | .9940 | .9950 | .9960 | .9970 | .9980 | .9990 | 1.0000 | 1.0010 | 1.0020 |
| 33 | .9910 | .9920 | .9930 | .9940 | .9950 | .9960 | .9970 | .9980 | .9990 | 1.0000 | 1.0010 | 1.0020 |
| 34 | .9910 | .9915 | .9925 | .9940 | .9950 | .9960 | .9970 | .9980 | .9990 | 1.0000 | 1.0010 | 1.0020 |
| 35 | .9900 | .9915 | .9925 | .9940 | .9940 | .9960 | .9970 | .9980 | .9990 | 1.0000 | 1.0010 | 1.0020 |
| 36 | .9900 | .9910 | .9920 | .9930 | .9940 | .9955 | .9965 | .9980 | .9990 | 1.0000 | 1.0010 | 1.0025 |
| 37 | .9890 | .9910 | .9920 | .9930 | .9940 | .9955 | .9965 | .9980 | .9990 | 1.0000 | 1.0010 | 1.0025 |
| 38 | .9890 | .9910 | .9920 | .9930 | .9940 | .9955 | .9965 | .9980 | .9990 | 1.0000 | 1.0010 | 1.0025 |
| 39 | .9890 | .9900 | .9915 | .9925 | .9940 | .9955 | .9965 | .9975 | .9990 | 1.0000 | 1.0010 | 1.0025 |
| 40 | .9890 | .9900 | .9915 | .9925 | .9940 | .9950 | .9960 | .9975 | .9990 | 1.0000 | 1.0010 | 1.0025 |

[1] The tabulated values are given to the nearest 0.0005.

TABLE II.—*Volume of milk and cream at various temperatures occupied by unit volume at 68° F. (20° C.)*—Continued.

| Per centage of butter fat. | Temperature (° F.). | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 74 | 76 | 78 | 80 | 82 | 84 | 86 | 88 | 90 | 92 | 94 | 96 |
| | Volume. | | | | | | | | | | | |
| 0.025 | 1.0005 | 1.0010 | 1.0010 | 1.0015 | 1.0020 | 1.0025 | 1.0030 | 1.0030 | 1.0035 | 1.0040 | 1.0045 | 1.0050 |
| 1 | 1.0005 | 1.0010 | 1.0010 | 1.0015 | 1.0020 | 1.0025 | 1.0030 | 1.0030 | 1.0035 | 1.0040 | 1.0045 | 1.0050 |
| 2 | 1.0010 | 1.0010 | 1.0015 | 1.0020 | 1.0020 | 1.0025 | 1.0030 | 1.0035 | 1.0040 | 1.0040 | 1.0045 | 1.0050 |
| 3 | 1.0010 | 1.0010 | 1.0015 | 1.0020 | 1.0020 | 1.0025 | 1.0030 | 1.0035 | 1.0040 | 1.0045 | 1.0045 | 1.0055 |
| 4 | 1.0010 | 1.0010 | 1.0015 | 1.0020 | 1.0020 | 1.0025 | 1.0030 | 1.0035 | 1.0040 | 1.0045 | 1.0050 | 1.0055 |
| 5 | 1.0010 | 1.0015 | 1.0020 | 1.0020 | 1.0025 | 1.0030 | 1.0035 | 1.0035 | 1.0045 | 1.0045 | 1.0050 | 1.0055 |
| 6 | 1.0010 | 1.0015 | 1.0020 | 1.0020 | 1.0025 | 1.0030 | 1.0035 | 1.0040 | 1.0045 | 1.0050 | 1.0050 | 1.0060 |
| 7 | 1.0010 | 1.0015 | 1.0020 | 1.0025 | 1.0025 | 1.0030 | 1.0035 | 1.0040 | 1.0045 | 1.0050 | 1.0055 | 1.0060 |
| 8 | 1.0010 | 1.0015 | 1.0020 | 1.0025 | 1.0030 | 1.0030 | 1.0035 | 1.0040 | 1.0045 | 1.0050 | 1.0055 | 1.0060 |
| 9 | 1.0010 | 1.0015 | 1.0020 | 1.0025 | 1.0030 | 1.0035 | 1.0040 | 1.0045 | 1.0050 | 1.0055 | 1.0060 | 1.0065 |
| 10 | 1.0015 | 1.0020 | 1.0025 | 1.0025 | 1.0030 | 1.0035 | 1.0040 | 1.0045 | 1.0050 | 1.0055 | 1.0060 | 1.0065 |
| 11 | 1.0015 | 1.0020 | 1.0025 | 1.0025 | 1.0030 | 1.0035 | 1.0040 | 1.0045 | 1.0055 | 1.0055 | 1.0065 | 1.0070 |
| 12 | 1.0015 | 1.0020 | 1.0025 | 1.0030 | 1.0030 | 1.0035 | 1.0040 | 1.0050 | 1.0055 | 1.0060 | 1.0065 | 1.0070 |
| 13 | 1.0015 | 1.0020 | 1.0025 | 1.0030 | 1.0035 | 1.0040 | 1.0045 | 1.0050 | 1.0055 | 1.0060 | 1.0065 | 1.0070 |
| 14 | 1.0015 | 1.0020 | 1.0025 | 1.0030 | 1.0035 | 1.0040 | 1.0045 | 1.0050 | 1.0055 | 1.0065 | 1.0070 | 1.0075 |
| 15 | 1.0015 | 1.0025 | 1.0030 | 1.0030 | 1.0035 | 1.0040 | 1.0045 | 1.0055 | 1.0060 | 1.0065 | 1.0070 | 1.0075 |
| 16 | 1.0015 | 1.0025 | 1.0030 | 1.0035 | 1.0040 | 1.0045 | 1.0050 | 1.0055 | 1.0060 | 1.0070 | 1.0075 | 1.0080 |
| 17 | 1.0015 | 1.0025 | 1.0030 | 1.0035 | 1.0040 | 1.0045 | 1.0050 | 1.0060 | 1.0060 | 1.0070 | 1.0075 | 1.0080 |
| 18 | 1.0020 | 1.0025 | 1.0030 | 1.0035 | 1.0040 | 1.0045 | 1.0055 | 1.0060 | 1.0065 | 1.0075 | 1.0080 | 1.0085 |
| 19 | 1.0020 | 1.0025 | 1.0030 | 1.0035 | 1.0045 | 1.0045 | 1.0055 | 1.0060 | 1.0065 | 1.0075 | 1.0080 | 1.0085 |
| 20 | 1.0020 | 1.0025 | 1.0030 | 1.0035 | 1.0045 | 1.0050 | 1.0055 | 1.0060 | 1.0070 | 1.0075 | 1.0085 | 1.0090 |
| 21 | 1.0020 | 1.0025 | 1.0030 | 1.0040 | 1.0045 | 1.0050 | 1.0060 | 1.0065 | 1.0070 | 1.0080 | 1.0085 | 1.0090 |
| 22 | 1.0020 | 1.0030 | 1.0035 | 1.0040 | 1.0050 | 1.0055 | 1.0060 | 1.0065 | 1.0075 | 1.0080 | 1.0090 | 1.0095 |
| 23 | 1.0020 | 1.0030 | 1.0035 | 1.0040 | 1.0050 | 1.0055 | 1.0065 | 1.0070 | 1.0075 | 1.0085 | 1.0090 | 1.0095 |
| 24 | 1.0020 | 1.0030 | 1.0035 | 1.0040 | 1.0050 | 1.0060 | 1.0065 | 1.0070 | 1.0080 | 1.0085 | 1.0095 | 1.0100 |
| 25 | 1.0020 | 1.0030 | 1.0035 | 1.0045 | 1.0055 | 1.0060 | 1.0070 | 1.0075 | 1.0080 | 1.0090 | 1.0095 | 1.0105 |
| 26 | 1.0025 | 1.0030 | 1.0040 | 1.0045 | 1.0055 | 1.0060 | 1.0070 | 1.0080 | 1.0085 | 1.0090 | 1.0100 | 1.0110 |
| 27 | 1.0025 | 1.0030 | 1.0040 | 1.0045 | 1.0055 | 1.0060 | 1.0070 | 1.0080 | 1.0085 | 1.0095 | 1.0100 | 1.0110 |
| 28 | 1.0025 | 1.0030 | 1.0040 | 1.0045 | 1.0055 | 1.0065 | 1.0075 | 1.0080 | 1.0090 | 1.0095 | 1.0105 | 1.0115 |
| 29 | 1.0025 | 1.0030 | 1.0040 | 1.0050 | 1.0060 | 1.0065 | 1.0075 | 1.0080 | 1.0090 | 1.0095 | 1.0105 | 1.0115 |
| 30 | 1.0025 | 1.0035 | 1.0045 | 1.0050 | 1.0060 | 1.0065 | 1.0080 | 1.0085 | 1.0095 | 1.0100 | 1.0110 | 1.0120 |
| 31 | 1.0025 | 1.0035 | 1.0045 | 1.0050 | 1.0060 | 1.0065 | 1.0080 | 1.0085 | 1.0095 | 1.0100 | 1.0110 | 1.0120 |
| 32 | 1.0030 | 1.0035 | 1.0045 | 1.0055 | 1.0065 | 1.0070 | 1.0085 | 1.0090 | 1.0100 | 1.0105 | 1.0115 | 1.0125 |
| 33 | 1.0030 | 1.0035 | 1.0045 | 1.0055 | 1.0065 | 1.0070 | 1.0085 | 1.0090 | 1.0100 | 1.0105 | 1.0115 | 1.0125 |
| 34 | 1.0030 | 1.0040 | 1.0050 | 1.0055 | 1.0065 | 1.0075 | 1.0085 | 1.0095 | 1.0105 | 1.0110 | 1.0120 | 1.0130 |
| 35 | 1.0030 | 1.0040 | 1.0050 | 1.0060 | 1.0070 | 1.0075 | 1.0090 | 1.0095 | 1.0105 | 1.0110 | 1.0120 | 1.0130 |
| 36 | 1.0035 | 1.0045 | 1.0055 | 1.0060 | 1.0070 | 1.0080 | 1.0090 | 1.0100 | 1.0110 | 1.0115 | 1.0125 | 1.0135 |
| 37 | 1.0035 | 1.0045 | 1.0055 | 1.0060 | 1.0070 | 1.0080 | 1.0095 | 1.0100 | 1.0110 | 1.0115 | 1.0125 | 1.0135 |
| 38 | 1.0035 | 1.0045 | 1.0055 | 1.0065 | 1.0075 | 1.0085 | 1.0095 | 1.0100 | 1.0115 | 1.0120 | 1.0130 | 1.0140 |
| 39 | 1.0035 | 1.0045 | 1.0055 | 1.0065 | 1.0075 | 1.0085 | 1.0095 | 1.0105 | 1.0115 | 1.0120 | 1.0130 | 1.0140 |
| 40 | 1.0035 | 1.0045 | 1.0055 | 1.0065 | 1.0075 | 1.0085 | 1.0095 | 1.0105 | 1.0115 | 1.0125 | 1.0130 | 1.0145 |

TABLE II.—*Volume of milk and cream at various temperatures occupied by unit volume at 68° F. (20° C.)*—Continued.

| Percentage of butter fat. | Temperature (° F.). | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 98 | 100 | 102 | 104 | 106 | 108 | 110 | 112 | 114 | 116 | 118 |
| | Volume. | | | | | | | | | | |
| 0.025 | 1.0055 | 1.0060 | 1.0065 | 1.0070 | 1.0075 | 1.0080 | 1.0085 | 1.0090 | 1.0095 | 1.0100 | 1.0105 |
| 1 | 1.0055 | 1.0060 | 1.0065 | 1.0070 | 1.0075 | 1.0080 | 1.0085 | 1.0090 | 1.0095 | 1.0100 | 1.0105 |
| 2 | 1.0055 | 1.0060 | 1.0065 | 1.0070 | 1.0075 | 1.0080 | 1.0085 | 1.0090 | 1.0095 | 1.0100 | 1.0110 |
| 3 | 1.0060 | 1.0065 | 1.0065 | 1.0070 | 1.0075 | 1.0080 | 1.0085 | 1.0090 | 1.0095 | 1.0100 | 1.0110 |
| 4 | 1.0060 | 1.0065 | 1.0065 | 1.0070 | 1.0075 | 1.0080 | 1.0085 | 1.0090 | 1.0095 | 1.0100 | 1.0110 |
| 5 | 1.0060 | 1.0065 | 1.0070 | 1.0075 | 1.0080 | 1.0085 | 1.0085 | 1.0090 | 1.0095 | 1.0100 | 1.0110 |
| 6 | 1.0060 | 1.0065 | 1.0070 | 1.0075 | 1.0080 | 1.0085 | 1.0090 | 1.0090 | 1.0095 | 1.0100 | 1.0110 |
| 7 | 1.0065 | 1.0070 | 1.0075 | 1.0075 | 1.0080 | 1.0085 | 1.0090 | 1.0095 | 1.0100 | 1.0105 | 1.0115 |
| 8 | 1.0065 | 1.0070 | 1.0075 | 1.0080 | 1.0085 | 1.0090 | 1.0095 | 1.0100 | 1.0105 | 1.0110 | 1.0115 |
| 9 | 1.0065 | 1.0070 | 1.0080 | 1.0080 | 1.0085 | 1.0090 | 1.0095 | 1.0100 | 1.0105 | 1.0110 | 1.0115 |
| 10 | 1.0070 | 1.0075 | 1.0080 | 1.0085 | 1.0090 | 1.0090 | 1.0095 | 1.0100 | 1.0105 | 1.0110 | 1.0115 |
| 11 | 1.0070 | 1.0075 | 1.0080 | 1.0085 | 1.0090 | 1.0095 | 1.0095 | 1.0100 | 1.0105 | 1.0110 | 1.0115 |
| 12 | 1.0075 | 1.0080 | 1.0085 | 1.0090 | 1.0095 | 1.0095 | 1.0105 | 1.0110 | 1.0115 | 1.0120 | 1.0125 |
| 13 | 1.0075 | 1.0080 | 1.0085 | 1.0090 | 1.0095 | 1.0100 | 1.0105 | 1.0110 | 1.0115 | 1.0120 | 1.0125 |
| 14 | 1.0080 | 1.0085 | 1.0090 | 1.0095 | 1.0100 | 1.0100 | 1.0110 | 1.0115 | 1.0120 | 1.0125 | 1.0130 |
| 15 | 1.0080 | 1.0085 | 1.0090 | 1.0095 | 1.0100 | 1.0105 | 1.0110 | 1.0115 | 1.0120 | 1.0125 | 1.0130 |
| 16 | 1.0085 | 1.0090 | 1.0095 | 1.0100 | 1.0105 | 1.0110 | 1.0115 | 1.0120 | 1.0125 | 1.0130 | 1.0135 |
| 17 | 1.0085 | 1.0090 | 1.0095 | 1.0105 | 1.0105 | 1.0115 | 1.0120 | 1.0125 | 1.0130 | 1.0135 | 1.0140 |
| 18 | 1.0090 | 1.0095 | 1.0100 | 1.0105 | 1.0110 | 1.0120 | 1.0125 | 1.0130 | 1.0135 | 1.0140 | 1.0145 |
| 19 | 1.0090 | 1.0095 | 1.0100 | 1.0110 | 1.0115 | 1.0120 | 1.0125 | 1.0130 | 1.0135 | 1.0140 | 1.0145 |
| 20 | 1.0095 | 1.0100 | 1.0105 | 1.0110 | 1.0115 | 1.0125 | 1.0130 | 1.0135 | 1.0140 | 1.0145 | 1.0150 |
| 21 | 1.0095 | 1.0100 | 1.0105 | 1.0115 | 1.0120 | 1.0125 | 1.0130 | 1.0135 | 1.0145 | 1.0150 | 1.0155 |
| 22 | 1.0100 | 1.0105 | 1.0110 | 1.0120 | 1.0125 | 1.0130 | 1.0135 | 1.0140 | 1.0150 | 1.0155 | 1.0160 |
| 23 | 1.0105 | 1.0105 | 1.0115 | 1.0120 | 1.0125 | 1.0130 | 1.0140 | 1.0145 | 1.0150 | 1.0155 | 1.0160 |
| 24 | 1.0105 | 1.0110 | 1.0120 | 1.0125 | 1.0130 | 1.0135 | 1.0145 | 1.0150 | 1.0155 | 1.0160 | 1.0165 |
| 25 | 1.0110 | 1.0115 | 1.0120 | 1.0130 | 1.0135 | 1.0140 | 1.0145 | 1.0150 | 1.0160 | 1.0165 | 1.0170 |
| 26 | 1.0115 | 1.0120 | 1.0125 | 1.0135 | 1.0140 | 1.0145 | 1.0155 | 1.0160 | 1.0165 | 1.0170 | 1.0180 |
| 27 | 1.0115 | 1.0120 | 1.0130 | 1.0135 | 1.0140 | 1.0150 | 1.0155 | 1.0160 | 1.0170 | 1.0170 | 1.0180 |
| 28 | 1.0120 | 1.0125 | 1.0130 | 1.0140 | 1.0145 | 1.0150 | 1.0160 | 1.0165 | 1.0175 | 1.0175 | 1.0185 |
| 29 | 1.0120 | 1.0130 | 1.0135 | 1.0140 | 1.0150 | 1.0155 | 1.0160 | 1.0165 | 1.0175 | 1.0180 | 1.0185 |
| 30 | 1.0125 | 1.0130 | 1.0135 | 1.0145 | 1.0155 | 1.0155 | 1.0165 | 1.0170 | 1.0175 | 1.0180 | 1.0190 |
| 31 | 1.0125 | 1.0135 | 1.0140 | 1.0145 | 1.0155 | 1.0160 | 1.0170 | 1.0175 | 1.0180 | 1.0185 | 1.0190 |
| 32 | 1.0130 | 1.0135 | 1.0140 | 1.0150 | 1.0160 | 1.0165 | 1.0170 | 1.0180 | 1.0185 | 1.0190 | 1.0195 |
| 33 | 1.0130 | 1.0140 | 1.0145 | 1.0155 | 1.0160 | 1.0165 | 1.0170 | 1.0180 | 1.0185 | 1.0190 | 1.0195 |
| 34 | 1.0135 | 1.0140 | 1.0150 | 1.0160 | 1.0165 | 1.0170 | 1.0175 | 1.0185 | 1.0190 | 1.0195 | 1.0200 |
| 35 | 1.0135 | 1.0145 | 1.0150 | 1.0160 | 1.0165 | 1.0170 | 1.0180 | 1.0190 | 1.0195 | 1.0200 | 1.0205 |
| 36 | 1.0140 | 1.0145 | 1.0155 | 1.0165 | 1.0170 | 1.0175 | 1.0185 | 1.0195 | 1.0200 | 1.0205 | 1.0210 |
| 37 | 1.0145 | 1.0150 | 1.0160 | 1.0165 | 1.0175 | 1.0180 | 1.0185 | 1.0195 | 1.0200 | 1.0205 | 1.0210 |
| 38 | 1.0150 | 1.0155 | 1.0165 | 1.0170 | 1.0175 | 1.0185 | 1.0190 | 1.0200 | 1.0210 | 1.0215 | 1.0215 |
| 39 | 1.0150 | 1.0160 | 1.0165 | 1.0170 | 1.0180 | 1.0185 | 1.0195 | 1.0205 | 1.0210 | 1.0215 | 1.0220 |
| 40 | 1.0155 | 1.0165 | 1.0170 | 1.0175 | 1.0185 | 1.0190 | 1.0200 | 1.0210 | 1.0215 | 1.0220 | 1.0230 |

TABLE II.—*Volume of milk and cream at various temperatures occupied by unit volume at 68° F. (20° C.)*—Continued.

| Percentage of butter fat. | (Temperature (° F.). | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 120 | 122 | 124 | 126 | 128 | 130 | 132 | 134 | 136 | 138 | 140 |
| | Volume. | | | | | | | | | | |
| 0.025 | 1.0110 | 1.0120 | 1.0125 | 1.0130 | 1.0135 | 1.0140 | 1.0145 | 1.0155 | 1.0160 | 1.0170 | 1.0175 |
| 1 | 1.0110 | 1.0120 | 1.0125 | 1.0130 | 1.0135 | 1.0140 | 1.0145 | 1.0155 | 1.0160 | 1.0170 | 1.0175 |
| 2 | 1.0115 | 1.0120 | 1.0125 | 1.0130 | 1.0135 | 1.0140 | 1.0145 | 1.0155 | 1.0160 | 1.0170 | 1.0175 |
| 3 | 1.0115 | 1.0120 | 1.0125 | 1.0130 | 1.0135 | 1.0140 | 1.0145 | 1.0155 | 1.0160 | 1.0170 | 1.0175 |
| 4 | 1.0115 | 1.0120 | 1.0125 | 1.0130 | 1.0135 | 1.0140 | 1.0145 | 1.0155 | 1.0160 | 1.0170 | 1.0175 |
| 5 | 1.0115 | 1.0120 | 1.0125 | 1.0130 | 1.0135 | 1.0140 | 1.0145 | 1.0155 | 1.0160 | 1.0170 | 1.0175 |
| 6 | 1.0115 | 1.0120 | 1.0125 | 1.0130 | 1.0135 | 1.0140 | 1.0145 | 1.0155 | 1.0160 | 1.0170 | 1.0175 |
| 7 | 1.0120 | 1.0125 | 1.0130 | 1.0135 | 1.0140 | 1.0145 | 1.0150 | 1.0155 | 1.0160 | 1.0170 | 1.0175 |
| 8 | 1.0120 | 1.0125 | 1.0130 | 1.0135 | 1.0140 | 1.0145 | 1.0150 | 1.0155 | 1.0165 | 1.0170 | 1.0175 |
| 9 | 1.0120 | 1.0130 | 1.0135 | 1.0140 | 1.0145 | 1.0150 | 1.0155 | 1.0160 | 1.0165 | 1.0170 | 1.0180 |
| 10 | 1.0120 | 1.0130 | 1.0135 | 1.0140 | 1.0145 | 1.0150 | 1.0155 | 1.0160 | 1.0165 | 1.0170 | 1.0180 |
| 11 | 1.0120 | 1.0130 | 1.0135 | 1.0140 | 1.0145 | 1.0150 | 1.0155 | 1.0160 | 1.0165 | 1.0170 | 1.0180 |
| 12 | 1.0130 | 1.0135 | 1.0140 | 1.0145 | 1.0150 | 1.0155 | 1.0160 | 1.0165 | 1.0170 | 1.0175 | 1.0180 |
| 13 | 1.0130 | 1.0135 | 1.0140 | 1.0145 | 1.0150 | 1.0155 | 1.0160 | 1.0165 | 1.0170 | 1.0175 | 1.0180 |
| 14 | 1.0135 | 1.0140 | 1.0145 | 1.0150 | 1.0155 | 1.0160 | 1.0165 | 1.0170 | 1.0175 | 1.0180 | 1.0185 |
| 15 | 1.0135 | 1.0140 | 1.0145 | 1.0150 | 1.0155 | 1.0160 | 1.0165 | 1.0170 | 1.0175 | 1.0180 | 1.0185 |
| 16 | 1.0140 | 1.0145 | 1.0150 | 1.0155 | 1.0160 | 1.0165 | 1.0170 | 1.0175 | 1.0180 | 1.0185 | 1.0190 |
| 17 | 1.0145 | 1.0150 | 1.0155 | 1.0160 | 1.0165 | 1.0170 | 1.0175 | 1.0175 | 1.0180 | 1.0185 | 1.0190 |
| 18 | 1.0150 | 1.0155 | 1.0160 | 1.0165 | 1.0170 | 1.0175 | 1.0180 | 1.0185 | 1.0185 | 1.0190 | 1.0195 |
| 19 | 1.0150 | 1.0155 | 1.0160 | 1.0165 | 1.0170 | 1.0175 | 1.0180 | 1.0185 | 1.0185 | 1.0190 | 1.0195 |
| 20 | 1.0155 | 1.0160 | 1.0165 | 1.0170 | 1.0175 | 1.0180 | 1.0185 | 1.0190 | 1.0195 | 1.0200 | 1.0205 |
| 21 | 1.0160 | 1.0165 | 1.0170 | 1.0175 | 1.0180 | 1.0185 | 1.0190 | 1.0190 | 1.0195 | 1.0200 | 1.0205 |
| 22 | 1.0165 | 1.0170 | 1.0175 | 1.0180 | 1.0185 | 1.0190 | 1.0190 | 1.0195 | 1.0200 | 1.0205 | 1.0210 |
| 23 | 1.0165 | 1.0170 | 1.0175 | 1.0180 | 1.0185 | 1.0190 | 1.0195 | 1.0195 | 1.0200 | 1.0205 | 1.0210 |
| 24 | 1.0170 | 1.0180 | 1.0185 | 1.0190 | 1.0195 | 1.0200 | 1.0205 | 1.0205 | 1.0210 | 1.0215 | 1.0220 |
| 25 | 1.0175 | 1.0180 | 1.0185 | 1.0190 | 1.0195 | 1.0200 | 1.0205 | 1.0210 | 1.0215 | 1.0220 | 1.0225 |
| 26 | 1.0185 | 1.0190 | 1.0195 | 1.0200 | 1.0205 | 1.0210 | 1.0215 | 1.0220 | 1.0225 | 1.0230 | 1.0235 |
| 27 | 1.0185 | 1.0190 | 1.0195 | 1.0200 | 1.0205 | 1.0210 | 1.0215 | 1.0220 | 1.0225 | 1.0230 | 1.0235 |
| 28 | 1.0190 | 1.0200 | 1.0205 | 1.0210 | 1.0215 | 1.0220 | 1.0225 | 1.0230 | 1.0235 | 1.0240 | 1.0245 |
| 29 | 1.0195 | 1.0200 | 1.0205 | 1.0210 | 1.0215 | 1.0220 | 1.0225 | 1.0230 | 1.0235 | 1.0240 | 1.0245 |
| 30 | 1.0195 | 1.0200 | 1.0205 | 1.0210 | 1.0215 | 1.0220 | 1.0225 | 1.0235 | 1.0240 | 1.0245 | 1.0250 |
| 31 | 1.0200 | 1.0205 | 1.0210 | 1.0215 | 1.0220 | 1.0225 | 1.0230 | 1.0235 | 1.0240 | 1.0245 | 1.0250 |
| 32 | 1.0205 | 1.0210 | 1.0215 | 1.0220 | 1.0225 | 1.0230 | 1.0235 | 1.0240 | 1.0245 | 1.0250 | 1.0255 |
| 33 | 1.0205 | 1.0210 | 1.0215 | 1.0220 | 1.0225 | 1.0230 | 1.0235 | 1.0240 | 1.0245 | 1.0250 | 1.0255 |
| 34 | 1.0210 | 1.0215 | 1.0220 | 1.0225 | 1.0230 | 1.0240 | 1.0245 | 1.0245 | 1.0250 | 1.0255 | 1.0260 |
| 35 | 1.0210 | 1.0215 | 1.0220 | 1.0225 | 1.0230 | 1.0240 | 1.0245 | 1.0250 | 1.0250 | 1.0255 | 1.0260 |
| 36 | 1.0215 | 1.0225 | 1.0230 | 1.0235 | 1.0240 | 1.0245 | 1.0250 | 1.0255 | 1.0260 | 1.0265 | 1.0270 |
| 37 | 1.0215 | 1.0225 | 1.0230 | 1.0235 | 1.0240 | 1.0245 | 1.0250 | 1.0255 | 1.0260 | 1.0265 | 1.0270 |
| 38 | 1.0220 | 1.0230 | 1.0235 | 1.0240 | 1.0245 | 1.0250 | 1.0255 | 1.0260 | 1.0265 | 1.0270 | 1.0280 |
| 39 | 1.0225 | 1.0235 | 1.0240 | 1.0245 | 1.0250 | 1.0255 | 1.0260 | 1.0265 | 1.0270 | 1.0275 | 1.0280 |
| 40 | 1.0235 | 1.0240 | 1.0245 | 1.0255 | 1.0260 | 1.0265 | 1.0270 | 1.0275 | 1.0280 | 1.0285 | 1.0290 |

### SPECIFIC GRAVITY OF MILK AND CREAM.

Table III covers the specific gravity of milk and cream determined at 68° F. (20° C.) in terms of water at the same temperature as unity.

TABLE III.—*Specific gravity of milk and cream corresponding to various percentages of butter fat at 68° F.*

| Per-centage of fat. | Specific gravity. | Per-centage of fat. | Specific gravity. | Per-centage of fat. | Specific gravity. | Per-centage of fat. | Specific gravity. |
|---|---|---|---|---|---|---|---|
| 0.025 | 1.037 | 11 | 1.024 | 21 | 1.012 | 31 | 1.003 |
| 1 | 1.036 | 12 | 1.022 | 22 | 1.011 | 32 | 1.002 |
| 2 | 1.035 | 13 | 1.020 | 23 | 1.010 | 33 | 1.001 |
| 3 | 1.034 | 14 | 1.019 | 24 | 1.009 | 34 | 1.000 |
| 4 | 1.032 | 15 | 1.018 | 25 | 1.008 | 35 | .999 |
| 5 | 1.031 | 16 | 1.017 | 26 | 1.008 | 36 | .999 |
| 6 | 1.030 | 17 | 1.016 | 27 | 1.007 | 37 | .998 |
| 7 | 1.029 | 18 | 1.015 | 28 | 1.006 | 38 | .997 |
| 8 | 1.027 | 19 | 1.014 | 29 | 1.005 | 39 | .996 |
| 9 | 1.026 | 20 | 1.013 | 30 | 1.004 | 40 | .995 |
| 10 | 1.025 | | | | | | |

### FREEZING POINT OF MILK.

The freezing point of milk depends upon its composition, but is always lower than that of water. The freezing point of market milk generally varies from 31° to 29° F. The addition of water to milk serves to raise the freezing point toward that of pure water, 32° F., while, on the other hand, the addition of fats, solids, etc., tends to lower the freezing point, as does also the increase in acidity. Upon these variations in the freezing point is based the cryoscopical method of determining the addition of water to milk.

### EFFFECT OF FREEZING ON MILK.

While the action of cold on milk at a temperature above the freezing point has no other effect than that of varying the density and viscosity, at a temperature below the freezing point it changes the chemical and physical composition.

According to Kasdorf,[1] when raw milk which was partly frozen at a temperature of 10.5° F., in the ordinary container, during transportation, it was found that ice first formed around the sides and at the bottom of the can; the central core contained most of the casein, sugar, and other mineral ingredients, while most of the fat was found in the top layer of the liquid portion.

When milk has been frozen gradually, without agitation, and thawed out clots will be found floating in the liquid, composed mostly of albumen and fat, which may be dissolved by cooking; on the other hand, if the milk is preserved in a frozen condition for three or four weeks these clots will be very hard to dissolve, and the difficulty experienced in dissolving them increases as the length of time the

[1] Kasdorf, Otto. Eis und Kälte in Molkereibetrieb. Leipzig, 1904, p. 20.

milk is preserved in a frozen state. For this reason the freezing of milk, for the purpose of transportation, has hitherto been little used.

If the milk is held at 32° F. for a few days, some types of bacteria may grow and multiply slowly. With a good quality of milk, i. e., that containing few bacteria, it may take weeks or even months for them to gain great headway. What few bacteria develop at low temperatures are of different species from those ordinarily found at the higher temperatures, and they may produce marked changes in the chemical composition of the milk without especially changing its appearance. Consequently, it is unsafe to assume that milk which has been held for several days at a low temperature is in good condition. According to Pennington[1] milk exposed continually to a temperature of 29° to 32° F. causes, after a lapse of from 7 to 21 days, the formation of small ice crystals which gradually increase until the milk is filled with them, and there may be an adherent layer on the walls of the vessel. The milk does not freeze solid. In spite of the fact that the milk was a semisolid mass of ice crystals, an enormous increase in bacterial content took place. Though the bacterial content was numerically in the hundreds of millions per cubic centimeter, there was neither taste nor odor to indicate that such was the case. Neither did the milk curdle when heated, and the unfitness of the milk for household purposes would not ordinarily be detected until the lactic acid bacteria decreased in numbers and the putrefactive bacteria began to develop.

#### THE INFLUENCE OF TEMPERATURE ON THE BACTERIOLOGICAL FLORA OF MILK.

Each species of bacterium found in milk and each particular variety has an upper and lower temperature limit beyond which it does not grow, and a certain temperature, called the optimum, at which it grows best.

The optimum temperature of most forms occurring in milk is between 70° and 100° F. As the temperature of milk is lowered the rate of growth is diminished until at 40° F. the multiplication is very slow and at a temperature just above the freezing point the development practically ceases; in fact, there is an apparent decrease in the number, at least for a short time. The action of cold at this temperature, however, does not totally destroy life in the bacteria, but causes them to lie dormant. When the temperature of the milk is raised they again begin to multiply. As an illustration of the relative variation in the growth of bacteria in milk held at different temperatures, one writer gives the data found in Table IV, in which 1 is assumed to represent the number of bacteria in the fresh milk, and the relative numbers which will be found at the end of 6, 12, 24, and 48 hours, at the two temperatures, are shown in the succeeding col-

[1] Pennington, Mary E. Bacterial growth and chemical changes in milk kept at low temperatures. Journal of Biological Chemistry, vol. 4, nos. 4 and 5, pp. 353–393. Baltimore, 1908.

umns. These figures are based on a number of actual counts and illustrate the effect of a difference of 18° on the multiplication of bacteria. If the milk had contained at the beginning 1,000 bacteria, the part held at the lower temperature would have contained at the end of 24 hours only 4,100 bacteria, while the other would have contained at the same stage 6,128,000. Table V, from Bulletin 133 (Extension Bulletin 8) of the agricultural experiment station of Nebraska, illustrates the importance of holding cream at low temperatures.

TABLE IV.—*Multiplication of bacteria in milk held at different temperatures.*[1]

| Milk held at— | Relative number of bacteria held at— | | | | |
|---|---|---|---|---|---|
| | 0 hours. | 6 hours. | 12 hours. | 24 hours. | 48 hours. |
| 50° F. | 1 | 1.2 | 1.5 | 4.1 | 6.2 |
| 68° F. | 1 | 1.7 | 24.2 | 6,128 | 357,499 |

[1] Rogers, Lore A. Bacteria in milk. U. S. Department of Agriculture, Farmers' Bulletin 490. Washington, D. C.

TABLE V.—*The effect of temperature on the growth of bacteria in cream.*

| Temperature of cream. | Time held. | Number of bacteria per c. c. | Temperature of cream. | Time held. | Number of bacteria per c. c. |
|---|---|---|---|---|---|
| °F. | *Hours.* | | °F. | *Hours.* | |
| 32 | 10 | 3,300 | 70 | 11 | 188,000 |
| 50 | 10 | 11,580 | 80 | 11 | 2,631,000 |
| 60 | 10½ | 15,120 | 90 | 11½ | 4,426,000 |

### THE INFLUENCE OF TIME ON THE BACTERIOLOGICAL FLORA OF MILK.

The influence of temperature and time bear certain definite relations to each other; hence, a study of one necessarily includes a study of the other. Table VI serves to illustrate the effect of time as well as temperature on the keeping qualities of milk. If the table is read downward we note the effect of temperature and if read across the effect of time. When milk is first drawn from the cow it usually contains bacteria, even though it is produced under sanitary conditions, and if held at the ordinary temperature of the surrounding air in a short while the bacteria will grow and increase in numbers so rapidly that when such milk reaches the consumer it will contain many thousand bacteria per cubic centimeter.

Conn furnishes an example of milk giving the following results:

| | Bacteria per c. c. |
|---|---|
| Milk drawn at 59° F. | 153,000 |
| After 1 hour | 616,000 |
| 2 hours | 539,000 |
| 4 hours | 680,000 |
| 7 hours | 1,020,000 |
| 9 hours | 2,040,000 |
| 24 hours | 85,000,000 |

According to Park,[1] two samples of milk maintained at different temperatures for 24, 48, 96, and 168 hours, respectively, showed the development of bacteria as indicated in Table VI. The first sample was obtained under the best possible conditions, while the second sample was obtained in the usual way. (The figures of the second sample are heavy face in the table.) When received the first sample contained 3,000 bacteria and the second 30,000 per cubic centimeter.

TABLE VI.—*Effect of time and temperature on the growth of bacteria in milk.*

| Temperature. | 24 hours. | 48 hours. | 96 hours. | 168 hours. |
|---|---|---|---|---|
| 32° F. (0° C.) | 2,400 | 2,100 | 1,850 | 1,400 |
| | **30,000** | **27,000** | **24,000** | **19,000** |
| 39° F. (4° C.) | 2,500 | 3,600 | 218,000 | 4,200,000 |
| | **38,000** | **56,000** | **4,300,000** | **38,000,000** |
| 42° F. (5° C.) | 2,600 | 3,600 | 400,000 | ..... |
| | **43,000** | **210,000** | **5,760,000** | ..... |
| 46° F. (6° C.) | 3,100 | 12,000 | 1,480,000 | ..... |
| | **42,000** | **360,000** | **12,200,000** | ..... |
| 50° F. (10° C.) | 11,600 | 540,000 | ..... | ..... |
| | **89,000** | **1,940,000** | ..... | ..... |
| 55° F. (13° C.) | 18,800 | 3,400,000 | ..... | ..... |
| | **187,000** | **38,000,000** | ..... | ..... |
| 60° F. (16° C.) | 180,000 | 28,000,000 | ..... | ..... |
| | **900,000** | **168,000,000** | ..... | ..... |
| 68° F. (20° C.) | 450,000 | 25,000,000,000 | ..... | ..... |
| | **4,000,000** | **25,000,000,000** | ..... | ..... |
| 86° F. (30° C.) | 1,400,000,000 | ..... | ..... | ..... |
| | **14,000,000,000** | ..... | ..... | ..... |
| 94° F. (35° C.) | 25,000,000,000 | ..... | ..... | ..... |
| | **25,000,000,000** | ..... | ..... | ..... |

In Table VI it will be noted that at 32° F. there is an actual decrease in the number of bacteria in both samples of milk during the 168 hours, while at all other temperatures there is an increase in the number of bacteria. Ordinarily the consumer receives milk when it is from 24 to 48 hours old; hence it becomes an easy matter to deliver the milk in good condition, providing the milk is produced under sanitary conditions and is properly cooled and held at a temperature of 50° F. or below. An examination of the tables and figure will show how intimately the two influences of time and temperature act and interact in relation to the multiplication of bacteria in milk. Figure 2 is a graphical representation of the relation of temperature to bacterial growth in milk, taken from Bulletin 26 of the Storrs (Conn.) Agricultural Experiment Station.[2]

At *a* is represented a single bacterium; at *b* is shown the progeny resulting from the growth of a single bacterium in 24 hours in milk kept at a temperature of 50° F.; at *c* is represented the progeny from a single bacterium in 24 hours in milk kept at 70° F. At 50° the multiplication was fivefold, at 70° the multiplication was seven

[1] Park, William Hallock. The great bacterial contamination of the milk of cities. Can it be lessened by the action of health authorities? Journal of Hygiene, vol. 1, no. 3, pp. 391–406. Cambridge, July, 1901.

[2] Conn, Herbert William. The relation of temperature to the keeping property of milk. Connecticut (Storrs) Agricultural Experiment Station Bul. 26. Storrs, 1903.

hundred and fifty fold. The figure shows graphically what a decided influence the dairyman can exert upon the keeping of his milk by a lowering of temperature only 20°.

From the foregoing it is obvious that proper refrigeration is of the utmost importance in the preservation of milk. In fact, without thorough cooling it is impracticable to keep milk for any considerable length of time in a condition that would justify its use for household purposes. It should be cooled to 50° F. or below as quickly as possible after it is drawn from the cow, as such cooling will at once check the increase in bacteria.




FIG. 2.—Graphical representation of the relation of temperature to bacterial growth in milk.

### COOLING BY MEANS OF SALT AND ICE MIXTURES.

Where a small amount of refrigeration is required it is often produced by a mixture of common salt and ice. The action of the mixture in lowering the temperature below 32° F. is as follows: When two solid bodies, as salt and ice, mix to form a liquid a certain amount of heat becomes latent, called the latent heat of solution. Since this latent heat is taken from the mixture itself the temperature falls correspondingly. The temperature obtained by a salt and ice mixture depends principally on the relative proportions of the mixture, and to a less extent on the rate at which the heat is supplied from the outside, the size of the ice lumps and salt particles, and the amount and density of the resulting brine. Hence it is impracticable to give other than approximate temperatures with fixed ratios of salt and ice. From the curve in figure 3 the approximate temperature resulting from different proportions, by weight, of salt and ice may be obtained. If, for example, we desire to know what temperature may be obtained by using a mixture of salt and ice containing 15 per cent of salt, follow the vertical line marked "15 per cent of

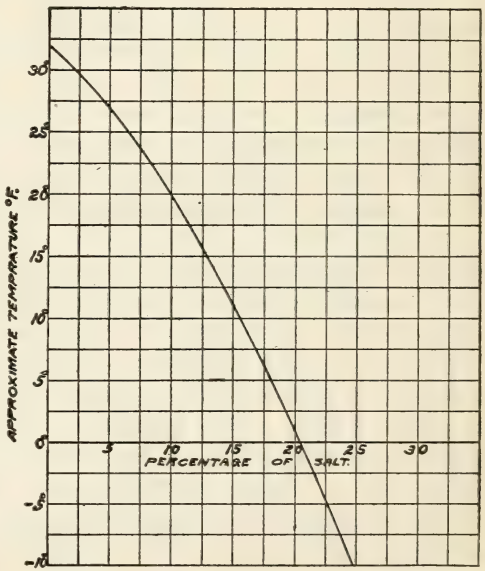



FIG. 3.—Approximate temperatures obtained with different proportions of salt.

salt" upward until it cuts the curve, then read opposite on the vertical line marked "Approximate temperature ° F., 11°." The curve in figure 3 was plotted from the figures in Table VII, which gives the approximate temperatures obtained with different proportions of salt and ice.

TABLE VII.—*Approximate temperatures obtained with different proportions of salt and ice.*

| Per cent of salt in mixture. | Temperature of mixture. | Per cent of salt in mixture. | Temperature of mixture. |
|---|---|---|---|
| | *° F.* | | *° F.* |
| 0 | 32 | 15 | 11 |
| 5 | 27 | 20 | 1.5 |
| 10 | 20 | 25 | —10 |

One pound of ice, in melting, absorbs 144 B. T. U. This is known as the latent heat of fusion of ice. Salt in dissolving also absorbs heat, called the latent heat of solution, which varies in amount, depending on the density and temperature of the resulting brine.

The heat of solution of salt in water at 32° F. varies from 58 to 16 B. T. U., depending on the final strength of the brine obtained. Table VIII gives the heat of solution of 1 pound of salt dissolved in water at 32° F. up to the concentration given by the numbers of pounds of salt dissolved in 100 pounds of water.

TABLE VIII.—*Refrigeration available with different proportions of ice and salt.*

| Salt per 100 pounds water. | Heat of solution. | Total heat of resulting solution. | Heat required per pound of mixture. | Salt per 100 pounds water. | Heat of solution. | Total heat of resulting solution. | Heat required per pound of mixture. |
|---|---|---|---|---|---|---|---|
| *Pounds.* | *B. T. U.* | *B. T. U.* | *B. T. U.* | *Pounds.* | *B. T. U.* | *B. T. U.* | *B. T. U.* |
| 1 | 58.0 | 14,458 | 143.0 | 20 | 27.0 | 14,940 | 124.5 |
| 5 | 49.7 | 14,668 | 139.5 | 25 | 22.5 | 14,962 | 119.5 |
| 10 | 40.5 | 14,806 | 134.5 | 30 | 19.1 | 14,973 | 115.0 |
| 15 | 33.0 | 14,895 | 129.5 | 35 | 16.4 | 14,974 | 111.0 |

The curve in figure 4, based on the percentage of salt, shows the amount of refrigeration available per pounds of ice and salt mixture. This curve was plotted from the figures given in Table VIII corrected to a percentage basis, which were calculated from the melting of ice at 32° F. into a liquid at the same temperature. If, however, the salt is added to the ice at a temperature varying from 32° F. or, if the resulting brine is allowed to escape at a temperature other than 32° F., the amount of available refrigeration must be corrected accordingly. These corrections are determined by multiplying weights, in pounds of salt and brine, by their respective specific heats and by their difference in temperature from 32° F. The specific heat of dry salt may be taken as 0.214, and as the specific heat of salt brine varies with its density, it may be obtained from Table IX or from curve figure 5, which is plotted from the figures contained in the table.

TABLE IX.—*Specific heat of brine with different percentages of salt.*

| Per cent of salt. | Specific heat of brine. | Per cent of salt. | Specific heat of brine. |
|---|---|---|---|
| 0 | 1.000 | 15 | 0.855 |
| 1 | .992 | 20 | .829 |
| 5 | .960 | 25 | .783 |
| 10 | .892 | | |

Usually salt when added to ice is of a higher temperature than that of the ice; consequently the correction for its heat above 32° F. must be subtracted from the available refrigeration shown by the curve, figure 4; and if the brine is allowed to escape at a temperature below 32° F. the refrigeration lost in the discharge brine must be subtracted, while, on the other hand, if the discharge brine is at a temperature higher than 32° F. the correction must be added.

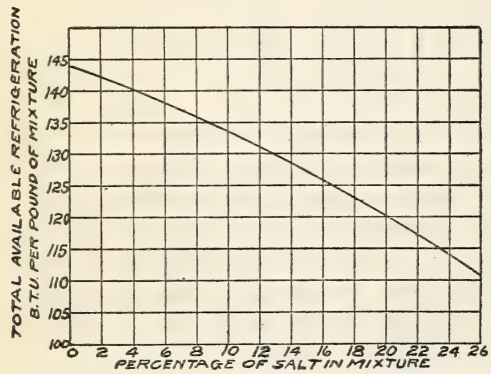



FIG. 4.—Refrigeration available with different percentages of salt.

If given amounts of ice and salt, at a temperature of 32° F. are mixed together and the mixture supplied with sufficient heat to melt the ice and dissolve the salt and raise the temperature of the resulting brine to the original temperature of 32° F., then the total amount of heat absorbed by the reaction will be the sum of the latent heat of the ice and the heat of solution of the salt to form the resulting brine of the density which will result from the particular proportion of salt and ice chosen. As an example, under the foregoing conditions, if 100 pounds of dry salt is added to 900 pounds of ice the total available refrigeration is $1,000 \times 133 = 133,000$ B. T. U. The available refrigeration per pound of mixture, 133 B. T. U., is taken from curve in figure 4. If the salt added is at a higher temperature than 32° F., say 60°

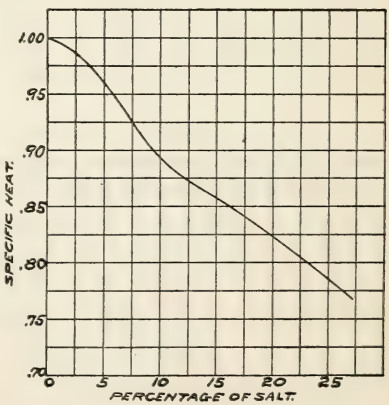



FIG. 5.—Specific heat of common salt brine, with different percentages of salt.

F., then the available refrigeration will be $133,000-[100\times0.214\ (60-32)]=132,401$ B. T. U., or 132.4 B. T. U. per pound of mixture. If the resulting brine is allowed to escape at 25° F., the available refrigeration is $133,000-[1,000\times0.892\ (32-25)]=126,756$ B. T. U., or 126.7 B. T. U per pound of mixture. Or, in other words, there is lost in the first case $100\times0.214\ (60-32)=599$ B. T. U., and in the second case, $1,000\times0.892\ (32-25)=6,244$ B. T. U., or a total loss, if the salt is added at 60° F. and the brine allowed to escape at 25° F., of $599+6,244=6,843$ B. T. U. Under these conditions the available refrigeration is $133,000-6,843=126,157$ B. T. U., or 126 B. T. U. per pound of mixture.

### REFRIGERATION AS APPLIED TO MILK PLANTS, CREAMERIES, AND DAIRIES.

The function of refrigerating apparatus, whether it is a refrigerating machine or a bunker filled with ice, is to provide a heat-absorbing medium which, after absorbing heat in the cold-storage room, may be removed. After it has been removed from the coolers it may be divested of its heat and allowed to return to the cooler for the purpose of absorbing more heat, as is the case when some volatile liquid is used, or it may be allowed to go to waste and a new supply introduced, as in the case of cooling with ice.

### ICE BUNKERS.

#### OVERHEAD BUNKERS.

One of the simplest methods of cooling a cold-storage room is that of an ice bunker, the principle of which is shown in figure 6 and consists of a water-tight floor located over the compartments to be cooled. The ice is piled on the floor through an opening at or near the top of the room and the cooling is effected by the natural circulation of air up and over the ice and down into the compartment in which the goods to be cooled are stored. The movement of air is naturally slow, as the power available is the difference between the weights of the ascending column of warm air and the descending column of cold air. As the air in contact with the ice is cooled it flows down into the room below, where it comes in contact with the warm goods in storage and absorbs heat from them, and as it becomes warmer is forced up to the bunker, where it is gradually cooled, thus producing a circulation. The movement of air may be increased and lower temperatures obtained by employing a fan driven by an outside source of power, or a mixture of salt and ice may be used in the bunker, in which case a lower temperature may be obtained, but in either case at the expense of a greater consumption of ice,

for, as previously stated, the use of a mixture of salt and ice in a refrigerator does not increase the cooling capacity of a given amount of ice, but the effect is to cause the ice to melt more rapidly and thus absorb heat more quickly. In other words, the melting point of ice is lowered when mixed with salt. One pound of ice in melting absorbs 144 heat units, either with or without salt. With salt the absorption is quickened, hence a lower temperature for a shorter time. Therefore there is no gain in efficiency by employing a mixture of salt and ice; in fact, there is a loss in efficiency due to the heat of solution.

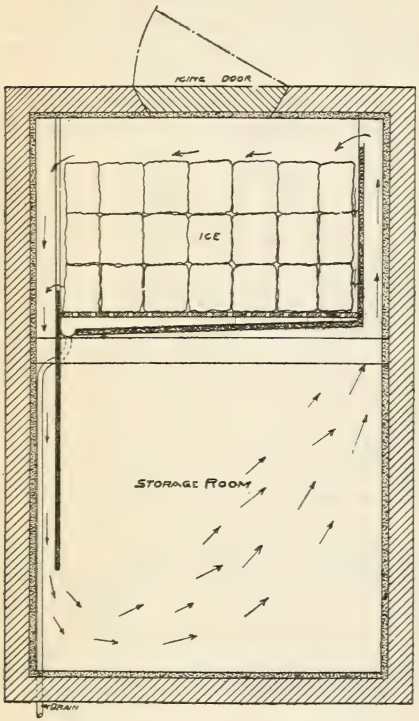



FIG. 6.—Overhead ice bunker.

Ice bunkers for cooling purposes, when located over the compartment to be cooled, should be made in the form of a box with one side removed, as shown in figure 6, in order to assist the air currents. With this form of construction the air, as it is gradually cooled, flows to the left down over the ice, while the warm air rises on the right to take its place. It is obvious that if the bunkers should be made in the form of a rectangular box the air would have a tendency to flow off in all directions and give rise to conflicting currents which would retard the circulation and for the same rate of circulation a greater difference in temperature between the air in the bunker and that in the compartment below would be required.

Ample spaces for air ducts should be provided between the sides of the bunker and the walls of the cold-storage compartment in order to permit the air to circulate freely. The cross-sectional area of the ducts should be from 10 to 15 per cent of the area of the ceiling. The floor of the bunker and the walls of the air ducts should be well insulated to prevent the too rapid cooling of the relatively warmer ascending air as well as that lying next the floor of the bunker. Rapid cooling of the air at these points tends to check the circulation by reducing the difference in temperature between the warm

air in the ducts and that in the bunker. With properly insulated bunkers and liberal-sized ducts the circulation should be sufficiently rapid to carry any air saturated with moisture to the ice bunker before its moisture can be precipitated by coming in contact with the cold walls of the storage room. With properly proportioned ducts and insulated walls the excess moisture will be precipitated in the ice bunkers and run off with the melted ice. If the air ducts and bunker walls and floor are not sufficiently insulated the excess of moisture will be condensed on them and will drip down on the goods in storage.

Provision should be made for thorough drainage and the drainpipe should be effectively trapped or sealed to prevent the outside air from entering the cold-storage room. An efficient water seal may be had by allowing the outer end of the drainpipe to extend below the surface of the water in a cooling tank outside the room, and as the water from the melted ice is approximately 32° F. it may be utilized for further refrigerating purposes.

As the melting point of ice is 32° F., it is obvious that, in a room cooled by ice, the temperature must necessarily be somewhat higher. In practice the temperatures obtained are rarely below 40° to 45° F. during warm weather. In addition to the disadvantage of the comparatively high temperatures obtained by using ice as the cooling medium in cold storage, the excessive moisture present in the air, together with the slop incident to its use, makes it undesirable. The nearer the temperature of the air in a room cooled by ice approaches that of the melting ice the more sluggish becomes the circulation and the higher the percentage of moisture contained in the air. Moisture in a cold-storage room favors the growth of molds and bacteria, which rot the floors and walls of the room, as well as the goods stored; consequently sensitive goods like dairy products are liable to be damaged by such conditions, especially if kept in storage for a considerable length of time. However, in small plants or on the farm, where goods are stored for a short period only and where ice may be had at a nominal cost, either natural or artificial, this method of cooling is employed to advantage.

Great care should be exercised to prevent any cross currents of air in the cooling room, for when such currents are present there is danger of the cold air and warm air coming in contact with each other, in which case condensation will be sure to take place on the cool surfaces of the walls and ducts, thereby preventing the displacement of the impure gases to be condensed on the surface of the ice in the bunker and removed with the drip.

It is very important that a positively guided circulation of air be maintained. In order for the cold air to be most effective it should

be admitted into the storage room at a low level, as indicated in figures 6 and 7. The cold air will then pass over the goods in storage, and as it becomes warmer will gradually rise to the bunker, where it is recooled. As natural circulation is brought about by the difference in temperature between the warm air and cold air, which is only a degree or two, advantage must be taken of the difference in height of the respective columns. The simplest and most effective way to accomplish this is to extend the cold-air duct to within about 2 feet of the floor. The inner side of this duct should be insulated to prevent condensation. The uptake duct should be similarly insulated and should extend from the bunker floor to near the ceiling of the room, leaving an area equal to the cross-sectional area of the warm-air duct. The warm-air duct should be located on the warmest wall of the room in order to take advantage of the natural air circulation, and for the same reason the cold-air duct should be on the coldest wall.

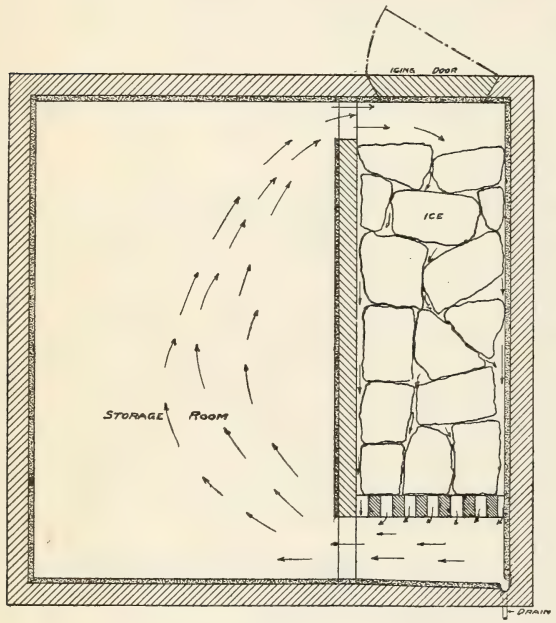



FIG. 7.—Side ice bunker.

SIDE BUNKERS.

Ice bunkers are often constructed as shown in figure 7, and the same care in construction and insulation should be observed as in the overhead type of bunker.

GRAVITY BRINE SYSTEM.

The system illustrated in figure 8 has made it possible to obtain temperatures considerably lower than can be obtained with the bunker system. It consists of a tank filled with ice and salt, in the proportions required to produce the desired temperatures, and an endless-pipe circuit.

The pipe is completely filled with a brine solution of the proper density to insure against freezing. It is customary to use a solution of calcium chlorid, as lower temperatures are obtained without danger of freezing and the corrosive action is less than that of com-

mon salt. The solution should not be stronger than the temperature to be maintained requires, as the specific heat of brine decreases as the strength of the solution increases. A part of the pipe coils are placed in the tank containing the mixture of salt and ice, and a part are led down into the cooling room below. The coils of pipe that are in the cooling room absorb heat from the stored goods

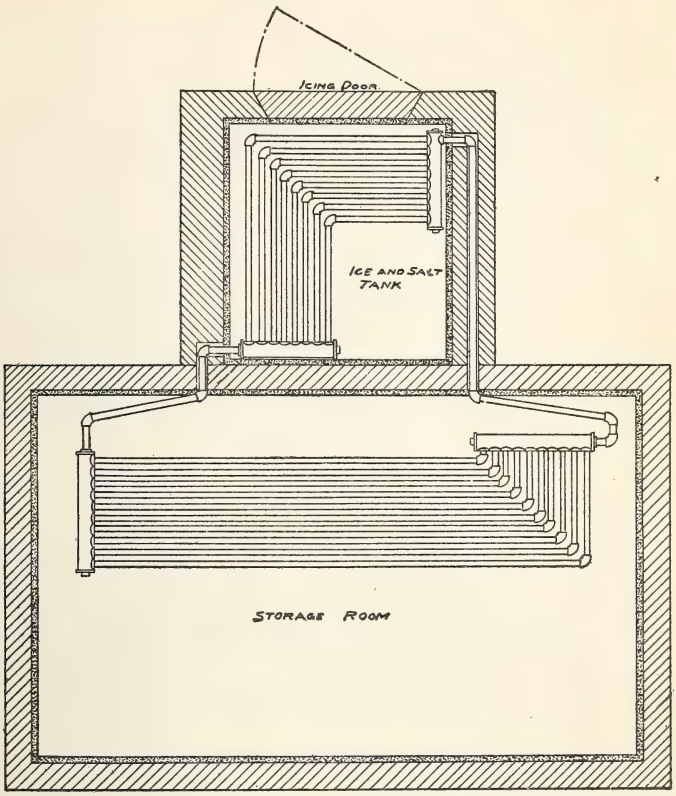



FIG. 8.—Gravity brine system.

and those in the tank give up heat to the freezing mixture of salt and ice.

The operation of this system is as follows: The brine in that part of the pipe circuit in the tank becomes heavier as it is cooled and flows down into the storage room, forcing the warmer and therefore lighter brine up into the coils in the tank. The heat absorbed in the storage room is transferred to the mixture in the tank by the natural circulation of the medium. This system is to a certain extent automatic in its operation, as an abnormal rise in temperature of the storage compartment from any cause increases the velocity of the brine circulation and therefore increases the re-

frigerating capacity of the system. With this system it is possible to prevent the air in the cold-storage compartment from becoming contaminated by contact with the melted ice and insanitary bunkers, as is the case when ice is used. In addition, a drier, purer air is maintained in the storage room.

In milk plants, creameries, and dairies, where the cooling is done in a comparatively short time, it is necessary to have a large storage tank for brine, which may be cooled in the afternoon or overnight and held for quick action when needed. As the temperature of the brine in the storage tank will gradually rise as the work of cooling the milk goes on, the volume required will depend on the amount of milk to be handled and the range of temperature through which it is to be cooled.

For example, if there are 1,000 pounds of milk to be cooled from an initial temperature of 90° F. to a final temperature of 35° F., the heat that must be removed is $1{,}000 \times 0.95\ (90-35) = 52{,}250$ B. T. U. Then, if the initial temperature of the brine is 25° F., the allowable rise in temperature will be 10°, and if the specific heat of the brine is 0.83, neglecting radiation, the amount necessary will be $\frac{52{,}250}{0.83 \times 10} = 6{,}292$ pounds, or 87.5 cubic feet. It is assumed above that the brine is pumped from a brine tank through some form of tubular cooler.

### CONSTRUCTION AND LOCATION OF COLD-STORAGE ROOMS.

In the construction of cold-storage rooms consideration should be given to the relations that the lateral dimensions bear to the cubical space of the room. This is an important factor in the construction of refrigerators and is one to which but little attention is given. It is important that the shape of the room should be given first consideration, and unless there are some local conditions that compel a different arrangement it should be built, as nearly as possible, in the form of a cube. This will present the smallest exterior surface for a given cubical space for any practical form of construction. For very small rooms, however, of less than 1,000 cubic feet capacity, it is impracticable to build them in the form of a cube, as the height should be 10 or 12 feet. This height affords a better circulation of air, and consequently a more uniform temperature, a purer, drier air, and more satisfactory refrigeration.

Where mechanical refrigeration is employed this height is necessary in order to provide space for the coil bunkers unless wall coils are used, in which case the height may be less. The circulation of air, however, is not so good with wall coils as with a bunker loft. If very cold temperatures are not required, as in the case of ordinary ice

boxes, a lower room may answer the purpose. As an illustration of the saving of material in construction and in refrigeration, let us consider two cold-storage rooms, each of 1,000 cubic feet capacity; one room to be in the form of a perfect cube, 10 by 10 by 10 feet = 1,000 cubic feet; the other room to be 10 by 6 feet by 16 feet 8 inches = 1,000 cubic feet. The total square feet of surface in the first room is 600; the total square feet of surface in the second room is 653; therefore, for the same cubical contents, the second room has 8.8 per cent more radiating surface and will require 8.8 per cent more material in construction.

The cold-storage room should be where it is protected as much as possible from the direct rays of the sun. Unless some natural protection is afforded, such as trees or buildings, the cold-storage room should be in the northeast corner of the building.

In the construction of a new plant advantage should be taken of the actual condition surrounding the proposed building site. Very often considerable may be gained by proper location of the building and arrangement of machinery.

For insulation of cold-storage rooms the reader is referred to the matter under the heading "Insulation."

## PRINCIPLES OF MECHANICAL REFRIGERATION.

When a solid or a liquid changes its state or condition, as when a solid is converted into a liquid or a liquid into a gas or vapor, the change of state or condition is in each case accompanied by the absorption of heat. This absorption of heat, as previously explained, is called "latent heat;" that is, heat that can not be measured by a thermometer; and in order to transfer a substance from one state to another it is only necessary to supply or extract heat. For instance, if we take 1 pound of ice at zero temperature, Fahrenheit scale, and apply heat, the temperature will rise until it reaches 32°. If we continue the application of heat the ice will begin to melt, and after we have supplied sufficient heat the 1 pound of ice will have changed to water at 32° F., the same temperature at which the ice commenced to melt. If the application of heat is continued the water will grow warmer, but at a slower rate. It now takes about double the amount of heat to raise the 1 pound 1 degree as water that it did to raise the 1 pound 1 degree as ice. In other words, the specific heat of water is approximately double that of ice.

When sufficient heat has been added to raise the 1 pound of water to a temperature of 212° F., another critical point is reached at which further application of heat to the water, under atmospheric pressure, will not increase its temperature, but changes it into steam at a temperature of 212°. Figure 9 shows graphically the relation of heat to temperature.

It will be noted from figure 9 that to raise the temperature of the 1 pound of ice from zero to the melting point (32° F.) 16 B. T. U were expended; in melting the ice, 144 B. T. U.; in raising the water to the boiling point, 180 B. T. U.; and to evaporate the water, 970.4 B. T. U. If the operation is reversed, the heat being extracted instead of being added, the curve will follow backward on itself to the starting point.

The latent heat of fusion and the latent heat of vaporization are represented on the diagram by the two lines parallel to the horizontal base line, the length of the lines representing to scale the amount of heat expended in molecular work in separating the molecules of the substances. Starting from the left, the rising lines represent the heat

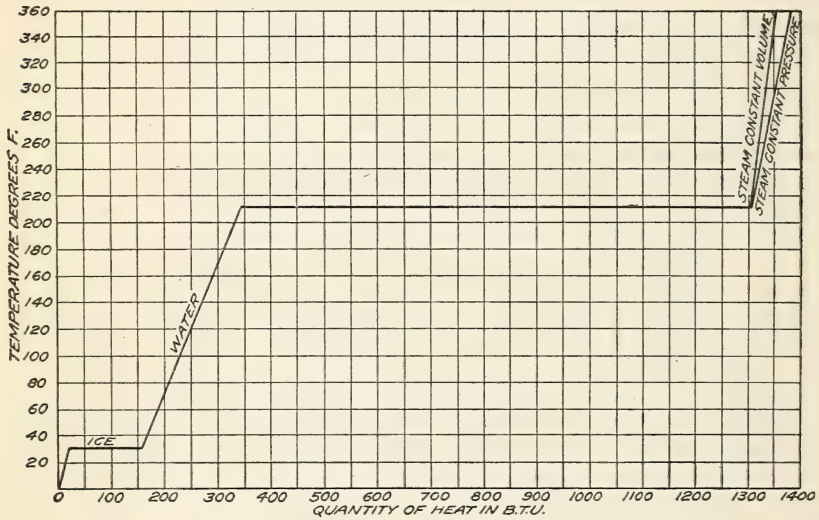



FIG. 9.—Diagram showing the relation of heat to temperature.

required to raise the temperature of the ice, water, steam at constant volume, and steam at constant pressure, respectively.

The same law applies to liquified anhydrous ammonia, carbon dioxid, and sulphur dioxid, which are the substances most commonly used in commercial refrigerating machines. These liquids are extremely volatile, their change of state takes place very rapidly, and their latent heat is absorbed at a corresponding rate. Their boiling point is sufficiently low under atmospheric or other conveniently produced pressure to give the temperature desired. Although the same principles underlie the use of all such fluids, their physical properties vary, and consequently demand different treatment in order to produce the best results.

The theoretical requirements of a good refrigerant are: A low boiling point at ordinary pressure, a large latent heat of vaporiza-

tion, and a small specific volume. A low boiling point is desirable, because it makes operation possible with comparatively low pressure in all parts of the system; therefore, the machines and accessories may be of lighter construction, with smaller loss of gas by leakage. As the latent heat of vaporization is, to a certain extent, a direct measure of the cooling effect, it is obvious that the greater the heat of vaporization the better the refrigerant. The specific volume of the refrigerating agent determines the volume of the cylinders of the compressor, consequently the size and weight of the machine.

In comparing the three refrigerating agents which are considered applicable to the dairying industry, viz, ammonia, carbon dioxid, and sulphur dioxid, it will be noted by referring to tables giving the main characteristics of the agents that, assuming the limits of operation are between 5° F. and 85° F., the absolute pressures are: Ammonia from 27 to 175 pounds, carbon dioxid from 290 to 1,000 pounds, and sulphur dioxid from 9 to 65 pounds. Taking the boiling points of the liquids at the temperature at which the liquid boils under atmospheric pressure, it will be noted that there is a wide difference in their boiling points as well as their latent heats of vaporization. Ammonia boils at 28.5° F. below zero and has a latent heat of vaporization of 572.8 B. T. U. Carbon dioxid boils at 110° F. below zero and has a latent heat of vaporization of 140 B. T. U. at a pressure of 182 pounds per square inch absolute. The latent heat at atmospheric pressure is not definitely known. Sulphur dioxid boils at a temperature of 14° F. and has a latent heat of vaporization of 162.2 B. T. U.

For practical purposes the value of a refrigerant depends upon its boiling point, its latent heat of vaporization, and upon the pressure at which it can be used.

To maintain a zero temperature with ammonia as the refrigerant an absolute pressure of 30 pounds per square inch is required in the evaporating coils; with carbon dioxid, 310 pounds absolute; and for sulphur dioxid, 10 pounds.

Ammonia has a much greater latent heat of vaporization and the working pressures are not excessive, but it has the disadvantage that it corrodes brass or any other copper alloy; consequently only iron or steel can be used in the construction of those parts of the machine with which the agent comes in contact. The pressures of carbon dioxid are so high as to cause trouble in keeping the stuffing box and joints tight. A relief valve is often placed in the high-pressure side of the system in order to protect it from excessive high pressures. It is noncorrosive, nonexplosive, and is not dangerous to life when diluted with air. The high pressures necessary, combined with the small specific volume of the gas, make it suitable for use with a very compact machine. As the lower pressure of

sulphur dioxid is below the atmospheric, any leakage of air will be into the system and will cause corrosion of the metal by forming sulphurous acid. The low pressures required in using sulphur dioxid as a refrigerant in connection with its large specific volume makes a large and cumbersome machine necessary. The ratios of the volumes of the cylinders necessary for a given capacity of machine, taking that of carbon dioxid as one, are approximately as follows: Carbon dioxid 1, ammonia 4.4, sulphur dioxid 13.

If either liquid ammonia, carbon dioxid, or sulphur dioxid is placed in a test tube, as shown in figure 10, it will boil under atmospheric pressure below the ordinary temperature of the surrounding air, and the heat of evaporation will pass from the surrounding air directly into the refrigerant. The air, therefore, will be refrigerated or cooled, due to the fact that its heat is taken up by the boiling liquid. In other words, the heat required for the evaporation of the liquid is extracted from the air. At the boiling point the refrigerant will absorb a definite amount of heat from the air to effect the vaporization of a definite amount of the liquid, the heat being absorbed directly through the walls of the test tube from the outside air. There will be a circulation of air around the test tube, as indicated by the arrows in the figure, due to the greater weight of the cooled film of air lying next the surface of the tube which flows down and away from the bottom of the vessel, allowing the warmer and therefore lighter air to rise and take its place at the top. Figure 10 embodies the principle of the direct-expansion system of refrigeration explained in detail later.

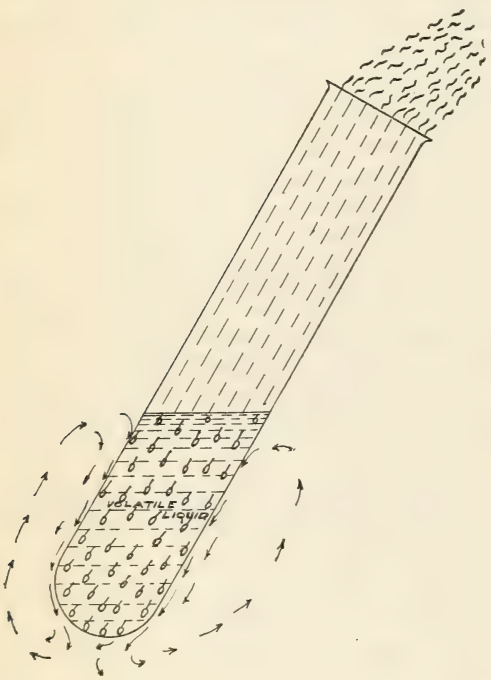



FIG. 10.

If the test tube containing the refrigerant is immersed in a second vessel containing a solution of brine, as shown in figure 11, the evaporating liquid will absorb heat from the surrounding medium just as in the preceding case, but in this case the surrounding medium is brine instead of air and the heat required to effect the vaporization

of the liquid is absorbed from the brine, which in turn is absorbed from the air by the brine. In this case there is a double transfer of heat, viz, from the air to the brine and from the brine to the evaporating liquid in the test tube. The cooling effect is assisted by the circulation within the brine itself, due to the difference in weight of the colder liquid in contact with the surface of the test tube, and that at a distance from it. The colder brine sinks to the bottom of the vessel and its place is taken by the warmer brine, thus producing a circulation as indicated by the arrows, whereas in the preceding case the heat from the surrounding air was absorbed directly by the refrigerant. In view of the fact that it is impracticable to lower the temperature of the brine to that of the refrigerant, the absorption of heat from the surrounding air by the brine is not so rapid as when the air is in direct contact with the walls of the vessel as in the preceding case. Figure 11 embodies the principles of the commercial brine-storage system of refrigeration, which will be discussed later.

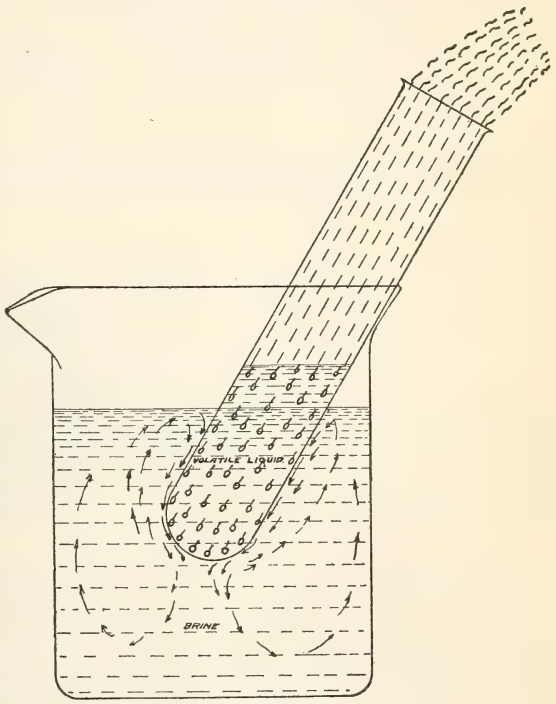



FIG. 11.

Going one step further toward the practical application of artificial refrigeration, imagine an arrangement as shown in figure 12, where the test tube in the foregoing illustration is replaced by a steel cask or drum, such as is commonly used for shipping ammonia, carbon dioxid, and other liquid gases, the tank corresponding to the beaker containing the brine. The liquid in the drum is under pressure, and if allowed to escape in a small stream through the throttling or expansion valve against atmospheric pressure it will evaporate in the coils located in the brine tank and the heat required for vaporization will be taken from the brine. If a pump were attached to the free end of the pipe the suction of the pump would tend to produce a vacuum, which action would accelerate

the evaporation of the liquid and the absorption of latent heat would go on faster than ever.

If it were not for the initial cost of the refrigerating medium this elementary form of refrigerating system, in which the refrigerant is allowed to escape to the atmosphere after evaporation, might find some commercial application, but as the refrigerants are expensive, such a system would be very costly to operate. Therefore, as the volatile liquids are valuable and can not be thrown away, if the reverse action takes place, that is, if the volatile gas is again converted into a liquid, it may be carried through the same cycle, over and over again indefinitely, and if it were possible to have no leakage one charge would be sufficient for all time.

## REFRIGERATING MACHINES.

### COMPRESSION SYSTEM.

In order to make the system illustrated in figure 12 commercially practical, it is necessary to provide some means for converting the

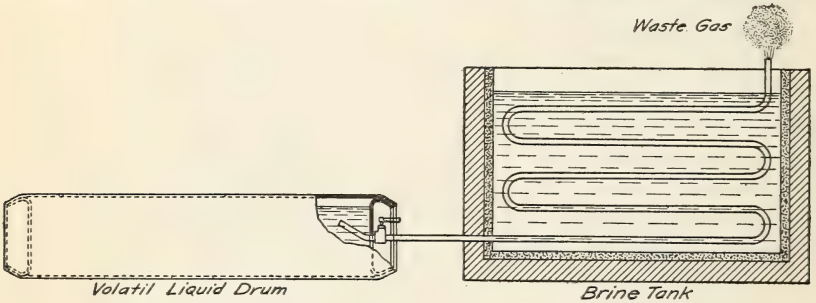



FIG. 12.

gasified refrigerant back into the liquid state in order that it may be again used for the purpose of absorbing heat. In other words, after the refrigerant has evaporated in the expansion coils and absorbed its fill of heat, much as a sponge sucks up its fill of water, the heat and water with which the refrigerating gas and sponge are respectively filled must be extracted before they can again perform the function of absorption. The water is forced out of the sponge by the simple application of pressure, but in the case of the refrigerating gas it becomes necessary not only to supply pressure, thereby raising the temperature of the gas by converting mechanical work into heat, but since the heat can be made to "flow" only from a relatively warmer to a relatively cooler substance, there must also be provided some cooling medium which will absorb the heat from the gas. Water being the cheapest and most convenient natural cooling medium, it is used almost entirely for this purpose.

Since the pressure and consequent temperature of the cold refrigerating gas returning from the expansion pipes must be raised before

the transfer of heat can be made to take place between it and the cooling water at ordinary temperatures, a compressor or a suitable gas pump must be used with a compression system of refrigeration. There must also be furnished a suitable cooling chamber or condenser in which the cooling water may be brought sufficiently near the refrigerating medium to allow the necessary heat to flow from the hot refrigerant to the cool water. Therefore the essential parts of a compression refrigerating system and their functions are:

*A compressor,* which is nothing more than a specially designed pump, which takes the gas from the evaporator coils and compresses it into the coils of the condenser, reducing the volume of the gas and increasing its temperature by changing work into heat.

*A condenser,* which consists of coils of pipe over which water is allowed to flow, or in some constructions the cooling water passes through an inner tube and the gas is discharged by the compressor into the annular space between the inner and the outer pipes. The heat imparted to the gas is given up to the cooling water, thereby liquefying the gas.

*An evaporator,* in which the liquid is allowed to boil and absorb heat from the surrounding media, again changing into the gaseous state. In other words, the process of refrigeration by means of the compression system is divided into three distinct stages, namely, compression, condensation, and expansion.[1]

*Compression.*—The gaseous refrigerant is drawn into the compressor or pump and there compressed to a pressure dependent upon the refrigerant and the temperature and quantity of cooling water used in the condenser. The latent heat of the vapor, that is, the quantity of heat imparted to it to effect its vaporization from a liquid to a vapor is converted into active or sensible heat during this compression.

*Condensation.*—The vapor is forced into the condenser coils under high pressure by the compressor, where the nonactive and sensible heat developed during compression is absorbed by the cooling water, thus removing from the vapor the heat required to keep it in the gaseous state, and thereby reconverting it into a liquid at the temperature and pressure existing in the condenser.

*Expansion.*—The refrigerant, after being liquefied in the coils of the condenser, is passed first to a liquid receiver and then into pipe coils through a throttling or expansion valve which is capable of being adjusted to allow the liquid to pass in small quantities. As there is a materially lower pressure maintained in these pipe coils by the com-

[1] In order to make the compression system perfectly reversible there is, in addition to the three stages mentioned above, a fourth, which consists in the reduction of the temperature of the liquid from the condenser temperature to that of the refrigerator, by the vaporization of a part of the liquid and by doing work by moving a piston.

pressor or pump, the liquefied refrigerant again expands into a vapor after passing into the coils, taking up from whatever substance surrounds it an amount of heat exactly equal to that which was given up during condensation. The vapor is again drawn back into the compressor, compressed, condensed, and expanded, the cycle of operation being repeated indefinitely with the same refrigerant.

Figure 13 presents diagrammatically the essential members of a compression-refrigerating system, in which *A* represents the direct expansion coils, in which the refrigerant is expanded after leaving the expansion valve *E*; *B*, the compressor or pump, which takes the warm gas or vapor from the expansion coils *A* and compresses them into the condenser *C*; *C*, the condenser for cooling and liquefying the gasified refrigerant; *R*, the receiver, into which the liquefied refrigerant flows from the condenser; *E*, the expansion or throttling valve, which controls the flow of the liquid refrigerant from the receiver *R* to the

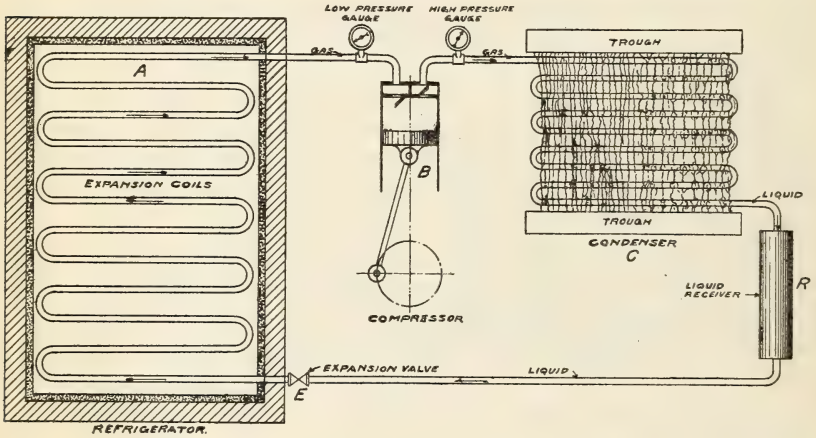



FIG. 13.—Elementary diagram of direct expansion system.

expansion coils *A*, where a materially lower pressure is maintained by the compressor, which causes the liquid to boil at a temperature sufficiently low to absorb heat from and therefore refrigerate the surrounding air.

In practice, however, the system is more elaborate, as will be noted by referring to figure 14, which shows a complete compression-refrigerating plant with all the accessories necessary for its operation.

## DIRECTIONS FOR INSTALLING, CHARGING, AND OPERATING INCLOSED TYPE OF AMMONIA COMPRESSION MACHINES.

### INSTALLING.

The compressor, condensor, and receiver should be located in a dry and well-lighted place where they will be accessible at all times for inspection and repairs. The liquid receiver and connections

should not be placed in the engine or boiler room, as the heat will evaporate part of the liquid and drive gas back into the condenser to be recondensed. Such an arrangement makes it necessary to install a larger condenser and to use more condensing water, and, in addition, the liquid goes into the evaporating system carrying its full quota of heat, thereby reducing its value.

The machine should be set on a well-built brick or concrete foundation, care being taken to have the machine perfectly level.

Before making the pipe connections all dirt and scale should be removed from the inside of the pipe and a pipe die run lightly over all threads exposed during shipment, after which they should be thoroughly washed with gasoline or benzine. The pipe fittings should be cleaned in the same way before connections are made. After the pipe and fittings have been thoroughly cleaned, apply a paste of litharge and glycerin to the threads and screw the pipe fittings up tight. Where soldered joints are required the threads on the pipe ends and fittings should be heated and thinned with solder before they are made up.

When the machine is in place and all pipe connections properly made, remove the cover of the crank case and fill with ammonia oil to the level of the crank shaft, or to the line on the frame of the compressor indicating the proper amount of oil required.

Disconnect the by-pass piping and close the main suction and discharge valves. Run the machine under no-load conditions for two hours to smooth up the bearings and make any adjustments that may be found necessary; then connect the by-pass on the discharge side. (Some manufacturers provide plugs in the by-pass piping, in which case it is not necessary to disconnect the piping.) Open the main discharge valve and all other valves on the ammonia system except the main suction valve and the by-pass valves, which should be closed.

Now start the machine again and pump air on the entire system to a pressure of about 150 pounds on the low-pressure gage. This should not be done, however, in one operation, on account of the possibility of melting the joints, due to the heat contained in the air. During the operation the machine should be stopped from time to time and all the apparatus examined in order to see that no undue heating occurs. Should parts of the apparatus be found unduly hot, the machine should remain at rest until the heated part is sufficiently cooled. Stop the machine and examine all piping and connections for leaks. This can best be done by applying soapsuds with a brush to all connections, and if there are any leaks they will be indicated by bubbles. If there is an ice-freezing tank in connection with the system, run water into the tank, completely submerging the coils,

and if there are any leaks they may be detected by air bubbles rising from the joints.

If the ammonia system has been found to be tight at the pressure of 150 pounds, close all expansion valves and again start the machine and pump air to a gage pressure of about 275 pounds, unless the discharge pipe gets very hot. As the low-pressure gage will not register so high a pressure as 275 pounds, it should be cut off when it has reached the limit of its scale. Allow the system to remain under this pressure for several hours and if the loss in pressure as shown by the gage, does not exceed 5 pounds, the system may be considered satisfactory so far as leakage is concerned.

Remove the short pieces of pipe between the suction valve and the machine and allow the air under pressure to escape quickly through the suction valve. Any dirt and scale that may be in the piping and which would otherwise be drawn into the machine with the suction gas will be blown out.

Before the system is charged with the refrigerant it is necessary to remove all air and moisture; otherwise the efficient operation of the machine will be seriously interfered with. Manufacturers usually provide special valves for discharging the air from the system, which is accomplished by starting up the machine and pumping the air out, the operation being just the reverse of that when working under service conditions. When a vacuum of about 26 inches has been obtained, stop the machine again and allow it to stand for several hours in order to determine if the system will maintain a vacuum. If the vacuum is maintained, the system is ready to be charged with the ammonia.

It is impossible in some cases to remove all the air from the system by means of the compressor, in which case it is desirable to insert the proper amount of refrigerant gradually. Often from 60 to 70 per cent of the full charge is inserted, and the air remaining in the system is allowed to escape through the purgecocks on the condenser until the ammonia shows, which will be detected by the very strong odor, and the escaping vapor will have the appearance of steam. An additional quantity of ammonia should then be inserted. This should be repeated once or twice a day until all the air has been displaced and the complete charge has been introduced.

### CHARGING.

To charge the machine, a drum of anhydrous ammonia is connected by a suitable pipe to the charging valve on the liquid receiver. Allow ammonia to enter the system through the charging valve until a pressure of about 15 pounds is recorded on the gage and then turn on the condensing water and start up the machine slowly at first.

The suction and discharge valves should be wide open while the machine is being charged. When one tank is emptied the charging valve should be closed and another tank placed in position, this being repeated until the system is sufficiently charged for work, when the charging valve should be closed and the main expansion valve adjusted. The ammonia drums should be weighed before and after being emptied or partially emptied, and a record kept of the amount necessary for charging. The glass gage on the liquid receiver will show the amount of liquid contained, and the pressure gages, as well as the gradual cooling of the brine in the refrigerator and the frost collecting on the expansion pipe, will indicate when a sufficient amount of the refrigerant has been inserted to start working.

### OPERATING.

After the machine has been started and the expansion valve adjusted, the temperature of the delivery pipe should be carefully noted, and should a tendency to heat be observed, the expansion valve should be opened wider, while, on the other hand, if it should become cold, the valve should be slightly closed, the adjustment being continued until the temperature of the pipe is the same as that of the cooling water leaving the condenser. If there is an insufficient charge of the refrigerant, the delivery pipe will become heated, even though the expansion valve is wide open.

Some of the signs which indicate the proper working of the plant, other than the fact that it is satisfactorily performing its refrigerating functions, are: The vibrations of the pointers on the high and low pressure gages; the frost on the exterior surface of the refrigerating pipes; the liquid refrigerant can be plainly heard passing through the expansion valve; and the difference in temperature between the liquid leaving the condenser and the final temperature of the cooling water, and between the refrigerator and the brine.

Should it become necessary to disconnect any part of the ammonia system for any reason, the ammonia must be pumped out of that part and stored in another part of the system. After making repairs, all the air must be exhausted from that part of the system before the ammonia is again allowed to enter.

*To pump ammonia out of the condenser.*—Close valves in the liquid pipe, the main suction, and discharge valves, and open the by-pass valves after draining the water from the condenser to prevent freezing and bursting of the pipes. Start the machine and pump out the ammonia until a partial vacuum is indicated by the high-pressure gage; then stop the machine and allow it to stand for two or three hours in order that any liquid ammonia lying in the pipes may have time to evaporate. Start up the machine again and pump down to a 25-inch

vacuum. After all ammonia has been exhausted from the system, close the valve in the ammonia discharge pipe and the condenser may then be disassembled.

*To pump the air out of condenser.*—The main suction and discharge valves should remain closed. The by-pass valve on the discharge side must be open and the one on the suction side closed. Manufacturers provide some means of opening the by-pass piping, either by a pipe tee or some form of cock; this should be opened and the machine run until all air is exhausted from the condenser. After all air has been exhausted the opening in the discharge by-pass must be closed and all valves set as they were originally. Ammonia may now be allowed to reenter the condenser, and after turning on the cooling water the plant is again ready for operation.

*To pump ammonia out of cold-storage room or cooler coils.*—All expansion valves must be closed, also the suction stop valves, except the suction stop valve on the coil which it is desired to pump out. This valve must be left open and the machine run until a 10 or 15 inch vacuum is obtained, when the machine should be stopped for two hours in order to allow any remaining liquid in the coils to evaporate. After the evaporation of the remaining liquid, start the machine again and pump down to a 25-inch vacuum. If all liquid has evaporated and the ammonia valves are tight, the coils should maintain the 25-inch vacuum until broken. The suction and discharge valves on the machine may now be closed and the part of the system which has been pumped out may be opened with safety.

*To pump air out of storage rooms or cooling coils.*—See that the main discharge stop valve is closed and remove the plug from tee or open cock, as the case may be, in the by-pass just below the discharge stop valve. The machine should be started slowly and run until all the air is exhausted from the coils, then stop machine and replace plug in tee or close cock in the by-pass.

*To pump out compressor.*—The same method as above is followed, except that the suction stop valve only is closed, as no part of the system except the compressor is to be pumped out.

### CARE OF REFRIGERATING MACHINERY.

In caring for machinery of any kind, one of the most important things is cleanliness, and especially is this true of refrigerating apparatus. If the cooling and condensing surfaces are allowed to become coated even slightly their heat-transferring efficiency will be lowered materially.

Where atmospheric condensers are used it is an easy matter when the surfaces become coated to clean them with a brush, provided the coating is not of the nature of a scale. If the substance is hard, it will be necessary to employ files or steel scrapers in removing the

scale. In double-pipe condensers and coolers it is not such an easy matter to clean them as it is necessary to take off a return bend from the end of the condenser or cooler in order to examine or clean them. This should be done frequently, and if the inner pipe is found to be coated with a soft substance it can be removed by the aid of an ordinary flue brush. If, however, the coating is in the form of scale, it will be necessary to bore it out on a lathe or tube-boring machine.

The life and satisfactory operation of all mechanical apparatus are dependent on proper care as well as on the original design. It is therefore necessary that such apparatus should receive frequent and careful inspection and prompt correction of all defects found. As cleanliness is essential for the satisfactory operation of machinery of all kinds, the wearing parts of the machine should be kept free from dirt and grit and the oilways open, well lubricated, and adjusted. The clearance of the pistons should be adjusted to a minimum, both in the steam and compressor cylinders.

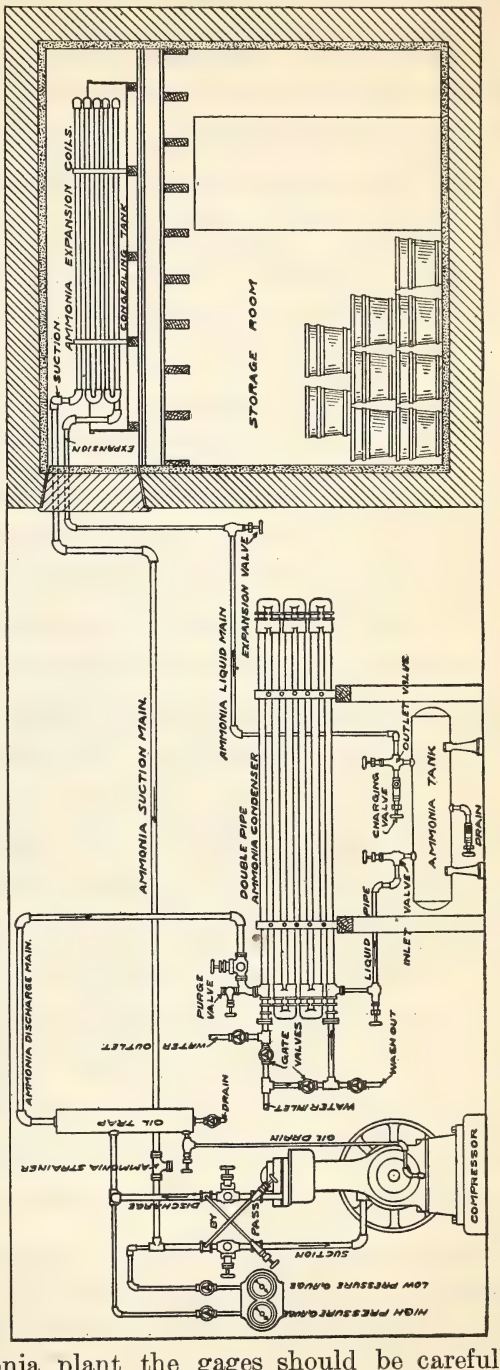



FIG. 14.—General arrangement of compression refrigerating system.

In operating an ammonia plant the gages should be carefully watched, as they are the indicators of the work being done. The

suction or low-pressure gage is controlled to a great extent by the expansion valve in the liquid line; consequently opening it will increase the low pressure, as the more the valve is opened the more gas will be pumped, providing the machine is run at a constant speed. If the speed of the compressor is increased, the amount of work will be proportionately increased provided the valves are large enough to handle the additional amount of gas, and vice versa. If the expansion valve is opened too wide for the speed at which the machine is running, the suction pipe will frost back to the machine and even the top of the compressor may become covered with frost. For satisfactory operation in a refrigerating plant a slight frost should cover the suction pipe close to the machine.

If the temperature of the brine in the cooling room is high, a corresponding high back pressure should be carried, and, on the other hand, a low brine temperature requires a low back pressure. Should a very low brine temperature be required, in addition to a low back pressure, the machine should be run at a faster speed, depending upon the relative capacity of the machine and the work to be done. It is necessary in the maintenance of low temperatures to keep the system free from air and deleterious gases, and plenty of cooling water should be supplied to the condenser while the plant is in operation.

For small plants the receiver should be of suitable size to hold all the refrigerating medium in a liquid form. It is usually located just below the condenser, or as near to it as local conditions will allow, so that the liquefied gas may return to the receiver by gravity.

In order that the amount of refrigerant contained in the system may be seen at a glance, the receiver should be provided with a glass gage similar to that placed on steam boilers to show the amount of water. This is especially true in small plants, where the attendant may not have had the necessary experience to enable him to judge of the amount of refrigerant in the system, and by observing the line of the liquid in the glass gage each time before starting up the compressor he will be able to note any loss of the refrigerant which he might not be able to do by other methods.

Some manufacturers, however, object to placing a gage of this kind on the receiver, as they contend that there is a possibility of loss of refrigerant by the breaking of the glass, and perhaps some danger should anhydrous ammonia be the refrigerant used. There is little danger, however, as the pressure and temperature is nearly constant and automatic ball stop valves may be used that will shut off the flow should the glass break.

It should be distinctly understood, however, that the foregoing refers to new plants and not to old ones. Under no circumstances should air at high pressure be pumped directly into an old system after repairing, or into one that has been standing idle for some time,

as an explosion is likely to occur, due to the vaporization of oil which may have lodged in the coils. The temperature of the air, when pumped into the system at a high pressure, is liable to exceed the flash point of the oil, resulting in an explosion.

For the same reason it is also dangerous, especially in the case of small, fast-running machines, to allow too much air to enter when pumping out the compressor in case it becomes necessary to pack the stuffing box; for should the attendant neglect to purge the condenser after the operation, the air in the system will be carried along with the ammonia gas, necessitating a higher pressure and a consequent higher temperature than would otherwise be attained; and should the temperature in the system get too great, there is danger of the oil which may be deposited in the coils reaching a point where flashing will take place, which will result in an explosion.

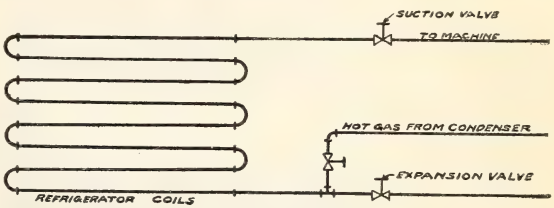



FIG. 15.—Conventional diagram.

In small installations usually found in milk plants, creameries, and dairies the condensers are of small dimensions; consequently, they can not hold large quantities of excess air. Hence great care should be taken to thoroughly purge the system of air when starting up after pumping out the compressor by blowing the air from the system. Manufacturers provide cocks for this purpose.

In cleansing old plants or those that have been shut down for some time from deposits of oil, it is a good plan to pump hot ammonia gas into the system. The gas should be taken from the line just before it enters the condenser. If taken from the top of the condenser, the gas will probably contain air and other impurities which would be liable to cause an explosion.

Referring to the conventional diagram, figure 15, the method of operation should be as follows: Connect a temporary pipe line with valve from the lowest part of the condenser or to the pipe line just before entering the condenser. Close the expansion valve and pump hot ammonia gas into the coils. Have the suction valve opened slightly and occasionally open it wide quickly to allow the oil to be carried out and deposited in the oil trap, from which it can be drawn off.

Before starting up the plant care should be taken to see that all oil cups are filled and the oil ways open, in order that all wearing surfaces may be well lubricated before the machine is started.

*To start.*—(1) Turn the water on the condenser and water jacket, and open the discharge valve on the compressor; (2) start the machine slowly at first and after the machine is in motion and the pressures are at proper point open the suction valve on the compressor gradually; (3) open the expansion valve sufficiently to give the required back pressure and the machine is in full operation.

*To stop.*—(1) Close the king valve which is between the receiver and the expansion valve and pump the low pressure to zero. This is considered better practice than closing the expansion valve each time the machine is stopped, thereby necessitating readjustment of the expansion valve upon starting up again; (2) open all drips and

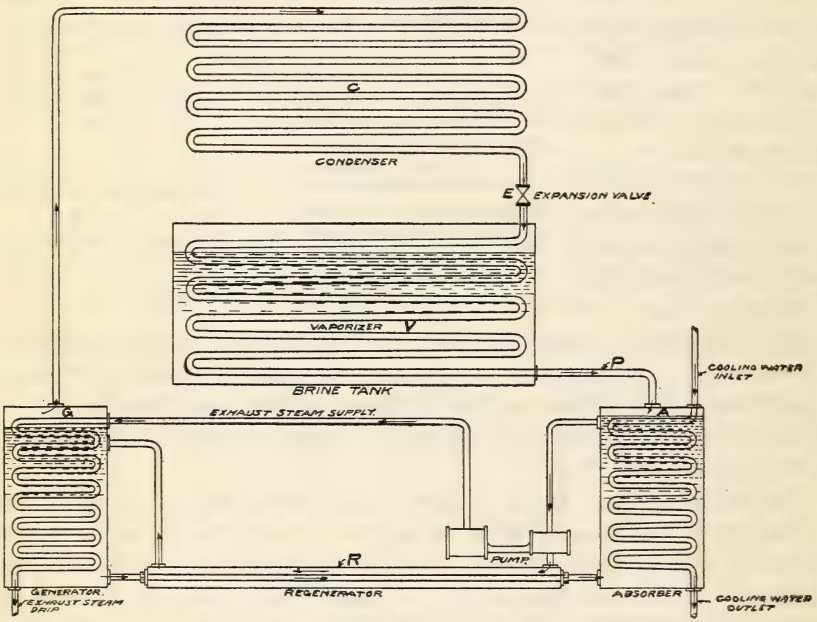



FIG. 16.—Elementary diagram of absorption system.

drains and shut down the machine; (3) close the suction and discharge valves, and all oil cups and water valves; (4) clean the machine thoroughly and examine all bolts and nuts to see that they are tight and see that the bearings are properly adjusted.

### VAPOR ABSORPTION SYSTEM.

The absorption and expulsion of ammonia gas by water forms the basic principle of the absorption process of refrigeration.

By referring to the elementary diagram, figure 16, the principles of this system of refrigeration will be understood. The generator *G* is an inclosed vessel which is partly filled with a solution of ammonia gas in water, under high pressure. Heat is applied to the generator,

usually by allowing low-pressure steam to flow through coils of pipe located in the generator, as indicated in the diagram, and the ammonia gas is driven off under pressure through the pipe into the condenser *C*, where it is condensed to a liquid when cooled by the condensing water. The ammonia, now in a liquid state, flows through the expansion valve *E* into the vaporizer *V*, where it is evaporated, the heat required for its evaporation being absorbed from the brine surrounding the coils. The vaporization of the liquid ammonia is made possible by the low pressure which is maintained in the evaporator due to the rapid absorption of the anhydrous ammonia by the weak aqua ammonia in the absorber. The brine is circulated about the coils of the vaporizer and from thence through the coolers, where it in turn absorbs heat from the goods in storage. The vaporizer coils may, however, be located directly in the compartment whose temperature it is desired to lower, in which case it is termed a direct expansion system. From the vaporizer the ammonia, now in the gaseous state, flows through the pipe *P* into the absorber *A*, which contains a weak solution of ammonia. The absorption of the ammonia gas by the weak solution in the absorber generates heat, which is carried off by the cooling water which is circulated through coils located in the absorber. The strong liquor thus formed in the absorber is delivered to the generator by a pump through the outer space in the regenerator coil *R*. The weak liquor from the generator is transferred to the absorber through the inner coil of the regenerator; consequently the liquid entering the generator is thus heated while that entering the absorber is cooled. The function of the regenerator is, therefore, to economize heat by transferring the heat from the weak to the strong liquor. The weak liquor coming from the generator, where it has been subjected to heat, goes into the absorber, where it is cooled by means of water circulation. The reverse is true in the case of the strong liquor; that is, the strong liquor comes from the absorber, where it has been cooled by water circulation, and goes into the generator, where it is heated. It is obvious that any heat transferred from the weak to the strong liquor represents just so much gain in economy.

As the only power required by the absorption system is that necessary to circulate the various liquids, it is inconsiderable when compared with that required by the compression system. Usually the exhaust steam from the pumps furnishes sufficient heat from the operation of the plant. The amount of cooling water, however, required by this system is greatly in excess of that required by a compression plant of the same capacity.

In practice, however, the vapor-absorption system of refrigeration is more complicated than shown in the elementary diagram. Figure

17 illustrates a general arrangement of a plant of this character with all the necessary accessories.

OPERATING ABSORPTION MACHINE.

*To start.*—(1) Start water circulating through machine; (2) start brine pump, making sure that the brine is circulating through cooler; (3) turn steam on gradually (steam should never be shut off entirely); (4) open gas line between cooler and absorber; (5) open weak-liquor valve, setting it at the usual running position; (6) start ammonia pump; (7) when generator pressure is about that usually carried, open valve in the dry gas line slowly, allowing the gas to enter the condenser; (8) open and set expansion valve.

*To stop.*—(1) Close steam valve on generator almost entirely (steam should never be shut off entirely); (2) close expansion valve; (3) shut down ammonia pump; (4) close weak-liquor valve; (5) shut

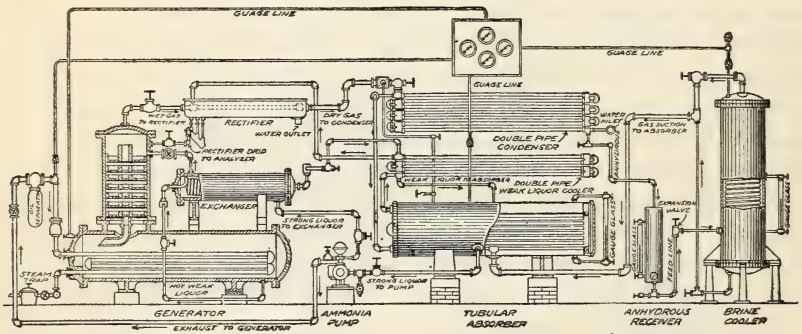



FIG. 17.—General arrangement of absorption refrigerating machine.

off cooler and absorber gas line; (6) close valve in dry gas line to condenser; (7) shut down brine pump; (8) shut off water supply.

The foregoing suggestions are of a general nature only and should be considered as such. The purpose for which a plant is used and the character of the trade supplied have considerable bearing on its operation and management; consequently the engineer in charge must determine on the best methods to employ in order to get the best results.

Figure 18 is intended to show, diagrammatically, the apparatus which is common to both the compression and absorption systems of refrigeration. As a matter of fact there are a number of accessories required in both systems for their successful operation which are not shown in the elementary diagram, as will be noted by referring to figures 14 and 17, which show the complete equipment of the two systems.

## METHODS OF UTILIZING REFRIGERATION.

There are two distinct methods of utilizing refrigeration, namely, the direct expansion system and the brine system.

### DIRECT-EXPANSION SYSTEM.

The coils of pipe in which the refrigerant is evaporated or expanded are placed directly in the room to be cooled; the heat necessary for the evaporation of the liquid refrigerant is, therefore, absorbed directly from the air, or whatever substances surround the tubes. The diagrammatic arrangement in figure 19 shows, in an elementary form, the commercial direct-expansion system. With a system of this kind the work of refrigeration practically ceases as soon as the plant is shut down; consequently it becomes necessary, in

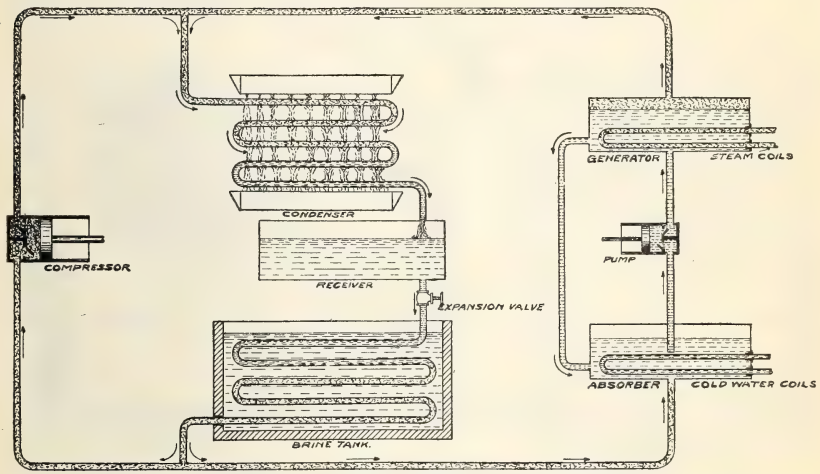



FIG. 18.—Diagrammatic arrangement showing equipment common to both the compression and absorption systems of refrigeration.

most cases, to run the plant continually or take the risk of losing the goods in storage.

For economical operation the suction pressure and evaporating temperature should be as high as possible. The suction pressure is governed by the temperature desired in the refrigerator. In milk plants, creameries, and dairies the suction pressure with an ammonia system should be about 15.67 pounds gage and a consequent gas temperature of 0° F.

Take, for example, a creamery cold-storage room 10 by 10 by 10 feet inside dimensions, which is of sufficient capacity to hold a week's output of butter from a creamery making 2,000 pounds daily. For the sake of simplicity, only the storage of butter is considered. It is assumed that the average outside temperature of the room is 75° F. and the inside temperature is to be maintained at 32° F. while the

machine is in operation. It is further assumed that the walls, floor, and ceiling are insulated for a heat transmission of 2 B. T. U. in 24 hours per square foot per degree difference of outside and inside temperature of room. The butter will come from the churn at about 58° F.

| | B. T. U. |
|---|---|
| The heat that will come through the insulation is $600\times2(75-32)$ | =51,600 |
| The heat to be removed from butter is $2,000\times0.5494(58-32)$ | =28,574 |
| | 80,174 |

Allowing 25 per cent to cover the additional work required for opening doors, lights, etc., we have a total of, say, 100,000 B. T. U. in 24 hours.

Assuming a back pressure of 15.67 pounds, which is equivalent to zero temperature ammonia, and a difference of temperature between

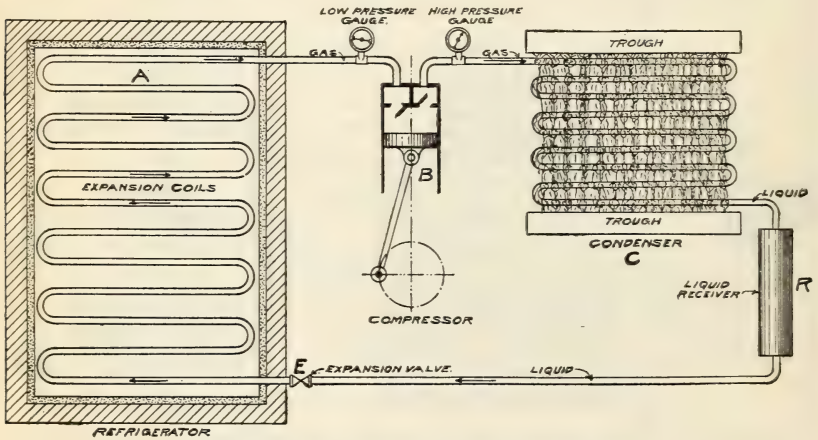



FIG. 19.—Elementary diagram of direct expansion system.

the refrigerant inside the piping and the layer of air surrounding the same of 10° F., and that 1 square foot of pipe surface will absorb about 10 B. T. U. per hour for each degree of difference between the inside and outside temperature of the pipe, the number of linear feet of $1\frac{1}{4}$-inch direct-expansion piping required for the room, is

$\frac{100,000\times2.3}{24\times10\times10}=96$, or 10.4 cubic feet of room space for each linear foot of piping. With the direct-expansion system the work of refrigeration practically ceases with the shutting down of the machine. The frost which has collected on the piping itself will tend to keep the room temperature down for a short time, but this is so small that it may be disregarded; consequently, it is necessary to run the direct-expansion plant continuously in order to maintain low temperatures.

### BRINE-CIRCULATING SYSTEM.

In this system the coils of pipe in which the refrigerant is expanded are located in a tank or specially designed brine cooler containing a solution of common salt, or calcium chlorid, of sufficient density to insure a low freezing point. After the brine has been reduced to a low temperature by the transfer of its heat to the expanding refrigerant, it is pumped through coils of pipe located in the room to be cooled, absorbing from the atmosphere a good part of its heat. It is then returned to the brine tank, or brine cooler, where it is recooled and again circulated through the rooms.

While the direct-expansion system is simple to operate, less expensive to install, and more efficient from the standpoint of heat transfer, nevertheless in the operation of small plants, applicable to the dairy industry where the plant proper is operated perhaps six or eight hours per day, it is more economical to install a brine system, in order

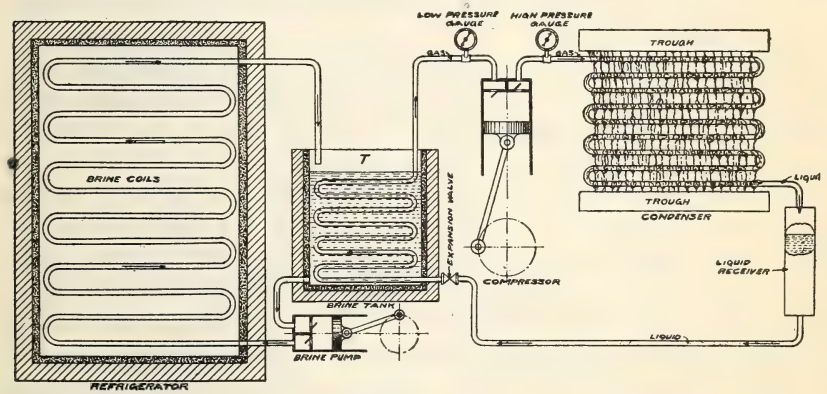



FIG. 20.—Elementary diagram of brine circulating system.

that some work of refrigeration may go on after the plant is shut down for the day, or in case of accident to the machinery. It is only necessary in the brine-circulating system to operate the brine pump for forcing the brine through the coils. The principles of this system are illustrated in figure 20. In addition to the usual members shown in the direct-expansion system, this system employs a brine tank, a series of brine coils, and a brine pump for circulating the brine through the coils. The cooling effect of the evaporating refrigerant is expended in the brine in this case, instead of directly in the cooling room, as indicated in the direct-expansion system, and the brine is circulated by the pump through the brine coils located in the cooling room. It should be borne in mind, however, that there is a double transfer of heat which cuts down the efficiency of the system to a certain extent, namely, from the air in the cooling room to the brine and from the brine to the expansion coils. The initial

cost of installing the brine-circulating system is more than that of the direct expansion, as it includes, in addition to the members of the direct-expansion system, a brine tank, brine coils, and a brine pump. The power necessary to operate the brine pump must also be considered. The excess power required for the operation of the brine-circulating system over that of the direct expansion of the same capacity is that necessary for pumping the brine from the tank through the cooling coils back to the tank; that required to overcome the friction of the brine in the pipes in traversing the above cycle; the additional refrigeration necessary to make up for the heating effect produced mechanically by circulating the brine, and the heat absorbed through the brine tank and through the brine piping; that required to make up for the reduced efficiency by having to operate the plant at a back pressure sufficiently low to obtain a correspondingly low temperature in the evaporator coils to compensate for the second heat transfer encountered between the air in the cold-storage room and the refrigerant.

The average difference in temperature between the circulating brine inside the piping and the surrounding air is, of course, much less than is the case when the refrigerant is expanded directly in the piping located in the cooling room, assuming the back pressure on the machine is the same in both cases. The difference in temperature between the refrigerant and brine depends on the insulation of the brine tank, piping outside of the rooms, etc., and as this varies between wide limits it is impracticable to calculate the amount of brine piping very closely on the basis of heat transfer, as was done in the case of direct expansion; consequently it is the common practice to install from one-half to twice as much brine piping in the brine-circulating system as would be used if direct expansion were employed. This allowance, however, is very liberal and is made to cover unfavorable cases where the insulation is poor; and further, any surplus piping serves to increase the efficiency of the plant.

Allowing 50 per cent more brine than direct expansion piping we have $96 \times 1.50 = 144$ linear feet of $1\frac{1}{4}$-inch piping required to do the same work as the direct expansion, or 7 cubic feet of storage space per linear foot of pipe. This amount of piping, when filled with brine, will contain 1.5 cubic feet. During the night the average difference in temperature between the inside and outside air will be about 43° F., therefore the heat that will come through the 600 square feet of surface of the room during 16 hours' shut-down period will be $\frac{600 \times 2 \times 43 \times 16}{24} = 34{,}400$ B. T. U.

If the initial temperature of the brine during the shut-down period is 16° while the final is 32°, giving a rise of 16 degrees, the heat that will be absorbed by the 1.5 cubic feet of brine contained

in the piping will be $1.5 \times 52 \times 16 = 1{,}248$ B. T. U. Consequently the hold-over period due to the brine in the piping is $\frac{1{,}248 \times 16}{34{,}400} = 0.58$ hour. If there are 2,000 pounds of butter stored in the room, it will also assist in increasing the time of shut down for a 3-degree rise in room and contents. The rise in temperature of the butter for a 16-hour shut down will be $\frac{34{,}400}{2{,}000 \times 0.5494} = 31.3$ degrees, or 3 degrees in 1.53 hours. Therefore, the total time the plant can be shut down for a 3-degree rise in temperature of room and contents is $0.58 + 1.53 = 2.1$ hours. Consequently it becomes necessary with this system to circulate the brine continuously. If, however, a sufficient volume of low-temperature brine is available for circulating through the coils, the refrigerating machine may be shut down for

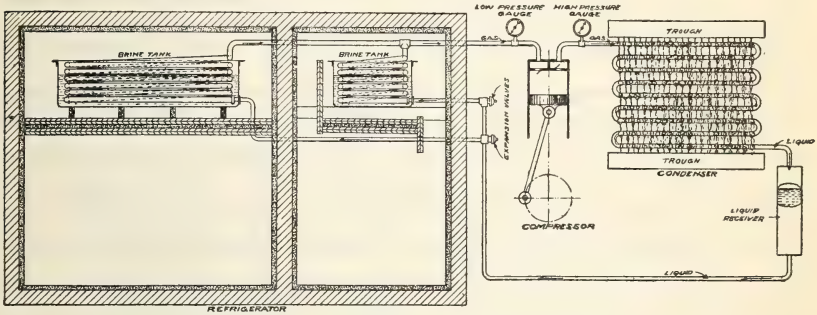



FIG. 21.—Elementary diagram of brine storage system.

a time, depending on the volume and temperature of the brine, by continuing the action of the pump.

### BRINE-STORAGE SYSTEM.

In place of the continuous brine coils employed in the brine-circulating system there is a modified brine system designed to give practically the same results (fig. 21). This is known as the brine-storage system and consists in replacing the main tank by several smaller ones located in the various compartments of the cold-storage plant. With an equipment of this kind the initial cost of the brine pump, the main brine tank, the necessary piping for brine circulation, and the brine-tank insulation are eliminated, as well as the power to operate the brine pump and the radiation losses through the brine tank and pipe insulation.

The heat-absorbing surfaces of the various small tanks entirely replace those of the brine coils. In practice, however, from one third to two-thirds of the direct expansion coils are placed outside of the brine, in direct contact with the air in the cold-storage room, in

order that the room may be cooled more quickly when the plant is started after being shut down for several hours, the remaining one-third or two-thirds, as the case may be, being submerged in the solution of brine.

Allowing a 3° rise in temperature of the air inside the room (32° to 35°) and a rise of calcium chlorid brine of 16° (6° to 22°), and as a cubic foot of brine will absorb about 52 B. T. U. per degree rise in temperature, the heat absorbed by the brine per cubic foot will be 52 (22–6) = 832 B. T. U. The volume of brine necessary to hold over temperature under the foregoing conditions will then be $\frac{34,400}{832} = 41.3$ cubic feet, or 1 cubic foot of brine for each 24.2 cubic feet of room space. In other words, the heat that will be absorbed by the 41.3 cubic feet of brine for a 16-degree rise will be $41.3 \times 52 \times 16 = 34,362$ B. T. U. Therefore, the hold-over period due to the brine is $\frac{34,362 \times 16}{34,400} = 16$ hours. The 2,000 pounds of butter in storage will hold the temperature for 2.1 hours for a 3-degree rise in the room temperature. Consequently the total hold-over period due to both the brine and the butter will be $16 + 2.1 = 18.1$ hours, or for a 16-hour shutdown the rise in room temperature will be 2.6°. During the hold-over period the average temperature difference between the air and the brine is about 19° F., and with a coefficient of heat transmission through the walls of the brine tanks of 1.5 B. T. U. per square foot per hour per degree difference in temperature of the brine and air, the effective square-foot surface of the tanks should not be less than $\frac{34,400}{16 \times 19 \times 1.5} = 75$; say two tanks 8 feet long, 1 foot wide, and $2\frac{1}{2}$ feet deep.

One linear foot of $1\frac{1}{4}$-inch pipe when submerged in still brine will absorb about 4 B. T. U. per hour per degree difference in temperature between the inside and outside of pipe, and as this difference is about 13.5°, the amount of $1\frac{1}{4}$-inch submerged piping required is $\frac{51,600}{8 \times 13.5 \times 4} = 117$ linear feet, or 58.5 feet per tank.

This method, however, is only a compromise between the brine-circulating and the direct-expansion systems, but has been found satisfactory and compares very favorably with the brine-circulating system of the same capacity. When used for holding over temperatures when the plant is shut down, either in case of breakdown of machinery or to avoid keeping an experienced attendant on duty continuously, the tank system for small plants possesses advantages over either the direct-expansion or brine-circulating systems.

### CONGEALING-TANK SYSTEM.

There is in use a modification of the brine-storage system known commercially as the "congealing-tank system." The principal advantage of this system is that by using a weak solution of brine a greater amount of refrigeration per cubic foot of brine is obtained by freezing a portion of the brine on the direct-expansion coils. This method, however, is not so efficient as the brine-storage system, due to the fact that the ice formed around the coils acts as an insulation. But the advantage gained in being able to store a greater amount of refrigeration in a small space often makes it advisable to install this system. In the operation of the congealing-tank system care should be taken not to let the volume of brine in the tanks freeze solid, for during the hold-over period some of the brine ice will melt, leaving a space between the ice and the sides and bottom of the tanks, and when starting up the refrigerating machine the smaller space between the ice and sides of the tanks will freeze first; consequently when the larger volume of brine at the bottom freezes the sides of the tank will be bulged out, due to the expansive force of the freezing brine. Therefore, ample space between the coils and sides of the tanks should be provided in order to allow the requisite amount of brine ice to form around the pipe coils at a safe distance from the sides. When a part of the brine solution is to be frozen, the volume of brine required is necessarily less than that required for a brine-storage tank system of the same capacity. In practice about one-half the volume of the brine storage is allowed for the congealing-tank system. Therefore the case under consideration will require two tanks 8 feet long, 2½ feet deep, and 6 inches wide. The effective surface of the two tanks is 93 square feet. The heat absorbed by each square foot of surface per hour during shutdown period is $\frac{34,400}{93\times16}=23.1$ B. T. U. Taking the coefficient of heat transmission in B. T. U. per degree difference in temperature as 1.5 per square foot per hour, the temperature difference necessary between the brine and air is $\frac{23.1}{1.5}=15.4°$.

With a 15 per cent solution, by weight, of common salt the freezing point is 12.2° F. Then the temperature of brine at the time the plant is shut down will be 12.2°, and at the time of starting up 27.6°. One cubic foot of the brine will absorb 59.2 B. T. U. per degree rise in temperature, and for a 15.4° rise $59.2\times15.4=911$ B. T. U. The volume of the two tanks is 20 cubic feet, consequently the heat absorbed by the brine will be $911\times20=18,220$ B. T. U., leaving $34,400-18,220=16,180$ B. T. U., to be absorbed by brine ice. Taking the latent heat of the brine ice as 122, the amount of brine to be frozen on the coils will be $\frac{16,180}{122}=132$ pounds. With 117 feet of submerged

1¼-inch pipe, this is equivalent to a uniform coating of ice $\frac{2}{64}$ inch thick.

In raising the temperature of 1 pound of a 15 per cent solution of common salt from the freezing temperature of 12.2° to 27.6°, 13 B. T. U. are required. For the same range in temperature of 1 pound of brine ice, approximately 135 B. T. U. are required. In other words, under the above conditions there is about 10 times more refrigeration available in the 1 pound of brine ice than there is in the 1 pound of brine. Consequently, by freezing a portion of the brine on the coils the hold-over period can be greatly increased.

### AIR-CIRCULATING SYSTEM.

There is a further modification of both the direct-expansion and brine-circulating systems, known as the indirect air-circulating system. This system is seldom used, except in connection with ice-cream hardening, where low temperatures must be obtained in a short time. It requires, in addition to the necessary members of the direct-expansion or brine systems, a fan, located in the cooling room over the coil bunkers and driven from without the room. The air is simply the circulating medium for producing the desired refrigeration and is forced by the fan over the cooling coils and down into the room below, where it comes in contact with and absorbs heat from the goods in storage. This results in a pure dry atmosphere, as the moisture content of the air is deposited on the surface of the coils in the form of ice and the greater portion of the microorganisms which were originally contained in the air are inclosed and rendered innocuous.

If the initial and final temperatures of the air, together with the corresponding moisture contents, are known, the refrigeration required for the simultaneous cooling and drying of the air can be ascertained. To cool the air alone necessitates the withdrawal, for every pound of air, of a number of B. T. U. equal to the product of the difference of temperature and the specific heat of air at constant pressure.

As it is common practice to measure air by volume, it is most convenient to express its specific heat in a unit of volume instead of weight. Since, however, the density of air varies with its temperature, it is impossible to obtain a value that will apply other than approximately to more than one condition. Taking, for example, air under standard conditions, density at 70° F., and a relative humidity of 70 per cent, a cubic foot weighs 0.07465 pound, and its specific heat is 0.0177.

If the initial temperature of the air in the room is 70° F. and it is cooled to, say, 20° F., the refrigeration to cool 1,000 cubic feet of air, neglecting the moisture, is $1{,}000 \times 0.0177\ (70-20) = 885$ B. T. U.

Considering the moisture in the air, the moisture content at 70° F. and 70 per cent relative humidity would be 5.596 grains per cubic foot, and at 20° F. for saturation there would be 1.235 grains. Therefore, there is eliminated per cubic foot $5.596-1.235=4.361$ grains, or for the 1,000 cubic feet, $1{,}000\times4.361=4{,}361$ grains or 0.623 pound. Consequently the refrigeration required is:

| | B. T. U. |
|---|---|
| Latent heat of liquefaction, $0.623\times970.4$ | 605 |
| Cooling from 70° to 32° F., $0.623\times(70-32)$ | 24 |
| Freezing, $0.623\times144$ | 90 |
| Cooling ice from 32° to 20° F., $0.623\times0.5(32-20)$ | 4 |
| | 723 |

The total heat, therefore, that must be removed in cooling the 1,000 cubic feet of air under the above conditions is $885+723=1{,}608$ B. T. U. In the case of cold storage the total amount of refrigeration required for air cooling depends, of course, on the number of times the air in the room is renewed in a given time. With the indirect-air system usually employed in the dairy industry the same air is kept in circulation to a great extent.

In all cold-storage work the air in the rooms must, of course, be cooled, but as the refrigeration required is generally small compared with that necessary for cooling the goods and in taking care of the heat that comes through the walls, floors, and ceiling, it is usually ignored and a liberal allowance made to cover this as well as lighting, presence of workman, poor workmanship, and other factors.

## INSULATION.

The word "insulate" is derived from the Latin word "insula," meaning "island." Therefore the significance of the definition of insulate is: To place alone or in a detached situation; separated by a nonconductor from other conducting bodies; having no communication with surrounding objects. Hence insulation in a cold-storage room is applied on the interior surface of the outside walls, under the roof, and under the lowest floor, to prevent, as far as possible, the transfer of heat from exterior heat-conducting bodies like the air and the ground.

With the increased application of refrigeration the problem of properly insulating the walls, floors, and ceilings of the cold-storage rooms is of the greatest importance and should be considered in the light of a permanent investment along with the building and equipment, the returns on which should be based on the saving effected by the lower operating cost.

It is evident that after the goods in storage have once been cooled to the desired temperature, it is then merely a question of supplying

sufficient refrigeration to take care of the heat which finds its way through the insulation of the walls, floors, and ceilings of the cold-storage rooms. The greater the efficiency of the insulation the less heat will get through from without. There is a limit, however, to the amount of insulation that should be installed, which is the point where the interest on the money invested in insulation, the repairs and depreciation on same, balances the saving in operating expenses.

There is no material known that will entirely prevent the passage of heat. However, there are some which offer a very high resistance, and are therefore termed nonconductors or insulators. The best heat insulators appear to be those that contain the greatest amount of entrapped air confined in the smallest possible air space.

The function of cold-storage insulation, then, is to prevent the outside heat from passing through the walls, floors, and ceiling into the interior of the cold room. Therefore the problem is to minimize the passage of heat by interposing in the walls, floors, and ceiling a material or construction which will resist the transfer of heat from the outer to the inner side of the room. The materials most commonly used for this purpose are the different varieties of cork products, mineral wool, hair felt, rock wool, vegetable fiber, sawdust, mill shavings, etc., used in combination with wood, cement, masonry, and air spaces. At one time it was common practice in the construction of buildings for cold-storage purposes to provide a series of air spaces in the walls, some of which were as much as 12 inches wide, the supposition being that they were dead-air spaces. As a matter of fact they were not. As the air in contact with the warmer surface became heated it rose, while that in contact with the cooler surface fell, thus producing a circulation tending to equalize the temperature of the sides of the air space. Dead air, however, is a good nonconductor, but unless the air spaces are properly proportioned, the above-mentioned air currents will be set up. Therefore, it is the present practice to fill in the spaces with some porous substance to break up the space into an indefinite number of small dead-air spaces which will effectually prevent circulation of the entrapped air. On the other hand, there is danger of packing the insulating material too closely, which will result in favoring the conduction of heat through the walls.

Sawdust and mill shavings are mentioned in the above partial list of insulating materials, but they are not to be considered among the best. They can be had in any part of the country, and often without cost, and if kept dry are good insulators. It is a very difficult problem, however, to keep them dry, and when used, great care should be exercised in the construction and workmanship of the walls in order to keep out the moisture.

Planing-mill shavings are better for insulating purposes than sawdust. They are elastic, do not settle rapidly, and will not absorb moisture as readily as sawdust, and, most important, can usually be had in very dry condition. They should be odorless, free from dirt, bark, and chips, and should be well packed into place to prevent future settling. About 9 pounds per cubic foot is considered the proper density to which they should be packed.

Sawdust has in the past been used to a great extent in rural districts for insulating the walls of small cold-storage buildings, due to the fact that it is available in most country districts, and generally may be had without cost. It is not a satisfactory material, however, for insulating purposes, as it is always more or less damp. The dampness not only destroys its insulating value, but it favors the growth of molds and bacteria, first in the sawdust itself and then in the walls of the building. The rotting and the consequent heating causes the sawdust to settle and leaves open spaces, which further weaken the insulation. It also furnishes an ideal nesting place for rats and mice, and the tendency of these rodents to carry matches into their nests and to start fires is well known. When sawdust or mill shavings are to be used they should be thoroughly dried before being put into the walls. Furthermore, if air is allowed to circulate in the shavings or sawdust moisture will be deposited in warm weather, and then, again, in cold weather it will dry out. This being repeated for several years will cause the boarding and shavings to rot. If, however, the shavings or sawdust is surrounded by waterproof paper and boarded, the condensation will not occur and deterioration will be prevented.

In deciding upon an insulating material for cold-storage purposes the following points should be carefully considered: Efficiency as a heat insulator; whether or not it will retain its efficiency indefinitely; structural strength; the effect of moisture; uniformity of insulating value; whether fireproof or not; space occupied; first cost; cost of installing, etc.

The greater portion of the refrigeration required for cooling cold-storage rooms is done to remove the heat that leaks through the walls, floors, and ceilings, and only a small part is required to cool the goods in storage. As previously stated, it is necessary to pump out, so to speak, the heat that enters from the outside after the goods are once cooled to the desired temperature.

Take for example a creamery cold-storage room 10 by 10 by 10 feet, inside dimensions, which is of sufficient capacity to hold a week's output of butter from a creamery making 2,000 pounds daily. The butter will come from the churn at approximately 58° F. The average outside temperature of room is assumed to be 75° F., and the inside temperature 32° F. It is further assumed that the walls, floors, and ceiling are insulated for a heat transmission of 3 B. T. U.

in 24 hours per square foot per degree difference of outside and inside temperatures of the room. The total surface of the room is 600 square feet. Then;

| | B. T. U. |
|---|---|
| The heat that will leak through into the room in 24 hours is 600×3 (75–32).. | 77,400 |
| The heat to be removed from the butter is 2,000×0.5494 [1] (58–32)..... | 28,574 |
| Total heat that will have to be removed..... | 105,974 |

From the above figures it will be noted that practically three-fourths of the refrigeration required in the average cooling room is done to remove the heat that leaks in through the insulation. Hence the necessity for good insulation.

It would seem from the foregoing that the more insulation put into the walls, floor, and ceiling the better, which is true when viewed from the standpoint of the refrigerating machine, as the more and better insulation used the less work the machine will have to do. But as insulation is expensive, a point is soon reached where the interest on the money invested, repairs, and depreciation on the insulating material balances the saving in reduced machine capacity and operating expenses. By installing more and better insulation, the saving in the capacity of the refrigerating machine is an item of considerable importance and one that has not been given the attention that it justifies.

From the data at hand, it appears that the most economical point to insulate for is a transmission in 24 hours of 2 B. T. U. per square foot per degree difference of outside and inside temperature of room, when the average outside temperature is 70° F. and the inside temperature of the room is 32° F. With an average outside temperature of 70° F. and an inside temperature of 0° F., the economical point is about 1½ B.T.U. In view of the fact that dairy products are extremely perishable when held at a temperature of 60° F. or above, the added security which the lowest heat transmission affords in order to hold over temperatures in case of the machinery breaking down, or where the plant is operated during the day only, makes the increased investment in insulation desirable. Good insulation not only permits operating the plant with the least refrigeration, power, time, and cost, but also helps to reduce fluctuations in room temperature. After shutting down the refrigerating plant the inflow of heat continues, but at a constantly decreasing rate. With a properly insulated room it will be several days before the inner air temperature will be near that of the outside temperature.

As an example of the saving effected by good insulation, take two cold-storage rooms of the same size and construction, say 10 by 10 by 10 feet. The walls are assumed to be built of brick 13 inches

[1] 0.5494 specific heat of butter.

thick, the floors and ceiling of concrete slabs 5 inches thick, the floors resting directly on the ground in both cases. The inside temperature of the two rooms is held at 30° F. by refrigeration and the average outside temperature is assumed to be 70° F. for 90 days. Suppose one building is not insulated at all and the other is insulated for a heat transmission of 2 B. T. U. per square foot of surface per 24 hours for each degree difference between inside and outside temperature.

The heat transmission through the 13-inch insulated brick walls is taken as 11.3 B. T. U. per square foot per degree difference of inside and outside temperature in 24 hours, and that for the 5-inch concrete slabs forming the floor and ceiling 28.8 B. T. U. In view of the earth offering a certain amount of protection to the floor slabs, which were assumed to rest on the ground in both cases, only half of the temperature difference between the outside and inside air is taken in computing the heat transfer through the floor in the uninsulated room. Then, for the uninsulated room the transmission will be:

| | B. T. U. |
|---|---|
| Brick walls, $400\times11.3\ (70-30)\times90$ | 16,272,000 |
| Ceiling, $100\times28.8\ (70-30)\times90$ | 10,368,000 |
| Floor, $100\times28.8\ (50-30)\times90$ | 5,184,000 |
| Total heat transmitted through the walls, floor, and ceiling | 31,824,000 |

This is equivalent to $\frac{31,824,000}{288,000}=110.5$ tons.

Therefore there will be 110.5 tons refrigeration required to remove the heat which comes through the walls, floor, and ceiling, and assuming that it cost $1 per ton to produce the refrigeration, it will amount to, in 90 days, $110.5\times1=\$110.50$. Now, in the case of the insulated building we have:

| | B. T. U. |
|---|---|
| Brick walls, $400\times2\ (70-30)\times90$ | 2,880,000 |
| Ceiling, $100\times2\ (70-30)\times90$ | 720,000 |
| Floor, $100\times2\ (70-30)\times90$ | 720,000 |
| Total heat transmitted through the walls, ceiling, and floor | 4,320,000 |

Equivalent to $\frac{4,320,000}{288,000}=15$ tons.

At a cost of $1 a ton for the refrigeration, it will amount to $15\times1=\$15$.

Therefore, there will be a loss of $\$110.50-\$15=\$95.50$ on the uninsulated building in 90 days. It will cost approximately 40 cents per square foot to insulate the above-described building for a heat transmission of 2 B. T. U. per square foot per degree difference of outside and inside temperature per 24 hours, or a total of $600\times0.40=\$240$. Consequently the insulation would pay for itself in about seven and a half months' operation.

As before stated, in order to obtain the maximum economy from a cold-storage plant, it is necessary that the investment and operating expenses should be so balanced that their sum is a minimum. The refrigerators or cold rooms may be constructed with a small amount or poor quality of insulation, requiring only a comparatively small investment, but on the other hand this saving must be offset by machinery of greater capacity and consequently more expensive both in initial cost and in the cost of operation. There is, however, a possibility of investing too much money in insulation, so that the fixed charges on same may be greater than the corresponding saving in investment in machinery and in operating expenses. Generally speaking, the cheaper the insulation the more should be used, and also the more expensive the refrigeration the more insulation should be installed.

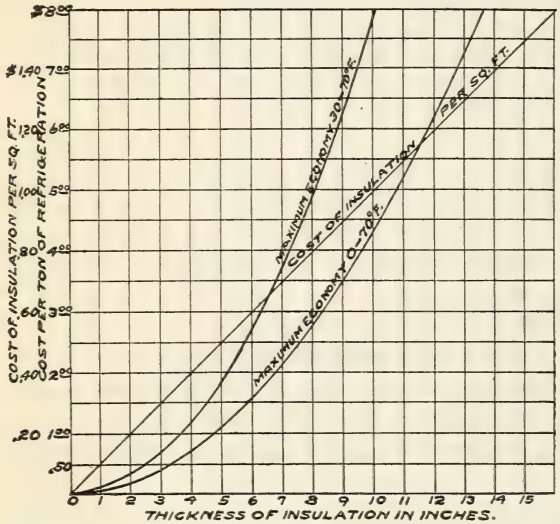



FIG. 22.—Economics of insulation.

In order to determine the relative amount of refrigeration and insulation to be used to obtain the greatest saving, it is necessary to consider the cost per ton of refrigeration; the cost per square foot of insulating material; the repairs and depreciation on insulating material; the insulating value of the material; the temperature maintained inside of room; and the average outside temperature.

The curve in figure 22 is based on the above-mentioned variables, which are assumed to be as follows:

Cost per ton of refrigeration.

Cost per square foot of insulation, 1 inch thick, installed, $0.10.

Repairs and depreciation of insulation material, 15 per cent.

Insulating value of material per board foot per 24 hours for each degree difference between the inside and outside temperature of room, 8 B. T. U.

Inside temperature of room, 30° F.

Average outside temperature of room, 70° F.

There is also shown a curve calculated from an inside room temperature of 0° and an average outside temperature of 70° F.

To use the curves in figure 22, suppose it costs $1 per ton per 24 hours to produce the refrigeration, and it is desired to know the amount of insulation that will give the maximum economy when the inside temperature of the room is at 30°F. and the average outside temperature is 70° F. Look on the left-hand side of the figure, under "Cost per ton of refrigeration," and follow the horizontal line opposite $1 until it crosses the curve marked "Maximum economy, 30° to 70° F.," then read at the bottom directly under the point where the curve cuts the horizontal line indicating $1 per ton, and it will be found to require 3¾ inches of insulation. If the inside temperature of the room had been 0° and the average outside temperature 70° F., the thickness of insulation required to obtain the maximum economy would have been 4¾ inches. Then the estimate cost of insulation per square foot is found by projecting a line vertically through the intersection of the curves and the horizontal line indicating a cost of $1 per ton of refrigeration, until it cuts the straight line marked "Cost of insulation per square foot," then reading on the left opposite this point and under "Cost of insulation per square foot," the cost per square foot of insulation is found to be 37½ and 47½ cents, respectively. It is assumed that the cost per square foot of insulation will be a constant in small cold-storage rooms of the size commonly used in milk plants. In the economical operation of a refrigerating plant the insulation is the most important point and great care should be exercised in its selection and installation. All exposed piping between the expansion valve and the suction side of the machine should be carefully insulated, as well as the walls of the refrigerator itself.

In the building of cold-storage rooms or boxes there is often used a construction of boards in combination with air spaces, and while cheap in first cost, in a few months in extreme cases the walls will begin to deteriorate and show increased losses. In a short time the piping in the box or room is not sufficient to hold the temperatures, and finally the capacity of the machine is not enough to do the work; whereas, with a sanitary box properly constructed of nonabsorbent material, no deterioration will occur after long and continued use. Consequently, it is very important wherever possible to eliminate wood in the construction and substitute for the walls hollow tile or brick.

When placing the insulation in the walls, floor, and ceiling of cold-storage rooms it is of the utmost importance that the workmanship be of the best. The insulation should be continuous. There should be no break in continuity where floor, walls, and ceiling meet. Each course of insulation should be well set up before the next course is put in place. In all cases the blocks of insulation should fit tightly

together. No cement should be used in the joints, but only on the back of the blocks.

The floors should be of concrete and should preferably be laid solidly on the insulating material. The insulating blocks should be laid in asphalt and coated over the top with hot asphalt and then 2 inches of concrete laid directly on the insulating material and finished with a coat of 1 inch of Portland cement.

In cold-storage rooms designed for storing milk and milk products an insulation should be used that will take a waterproof interior finish, such as Portland or other hydraulic cement, or vitrified hollow tile laid up in cement mortar. This construction permits of being thoroughly washed out with either hot or cold water without injury to it or to the insulation proper.

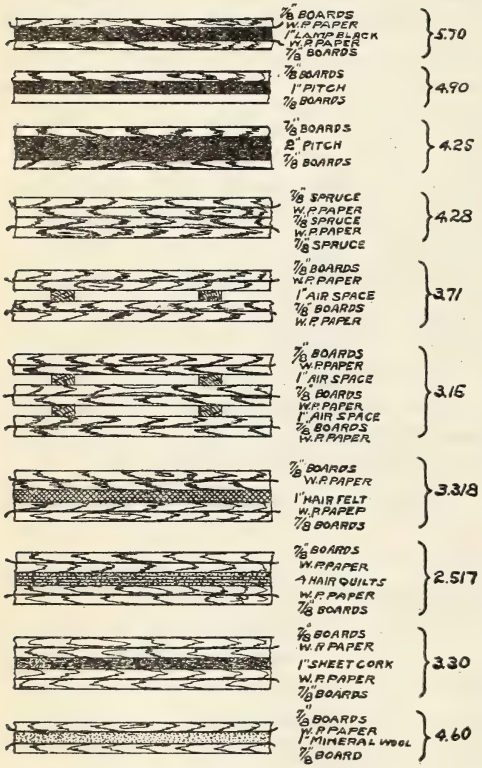



FIG. 23.—B. T. U. transmitted per square foot per 24 hours per degree difference in temperature.

Wooden floors have proved very unsatisfactory, as they rot out in a comparatively short time, due to the fact that they are more or less absorbent and can not be readily cleaned and therefore retain odors that may be injurious to delicate goods. The ability to keep storage rooms, especially where used for storing dairy products, in a sanitary condition by thoroughly washing will be appreciated by dairymen.

When brick or concrete are used in construction the exterior of the walls should be coated with some efficient waterproofing compound; the walls should be thoroughly dried out, however, before the compound is applied. The customary method has been to waterproof the interior of the walls, allowing the outside moisture to soak through the walls until it reaches the inner film of the waterproofing compound. It is much better to waterproof the outside surface of the walls, thereby preventing the moisture from penetrating through to the inner side. In cold-storage rooms the doors perhaps afford the weakest point in the insulation. While their insulation is of

importance, their tightness and ability to be operated quickly is vastly more so. A poor-fitting door that allows the outside air to leak into the room is a source of endless expense; consequently great care should be exercised in fitting doors in place. Usually it is economy to buy a good design of commercial door, as it will fit better and not be so liable to warp as a door built by the local carpenter. With slow and heavily moving doors which bind and work badly there is a tendency on the part of the workmen to leave them open, allowing the warm outside air to rush in and replace the cold air. Equal care should be exercised in the construction of windows in the walls of cold-storage rooms. They should be constructed of three plates of glass with two half-inch air spaces. The glass plates should be carefully set in felt and made perfectly air-tight. The drawings of typical constructions of cold-storage insulations with their insulating values are shown in figs. 23, 24, 25, 26, and 27; they are taken from tests made by different authorities.

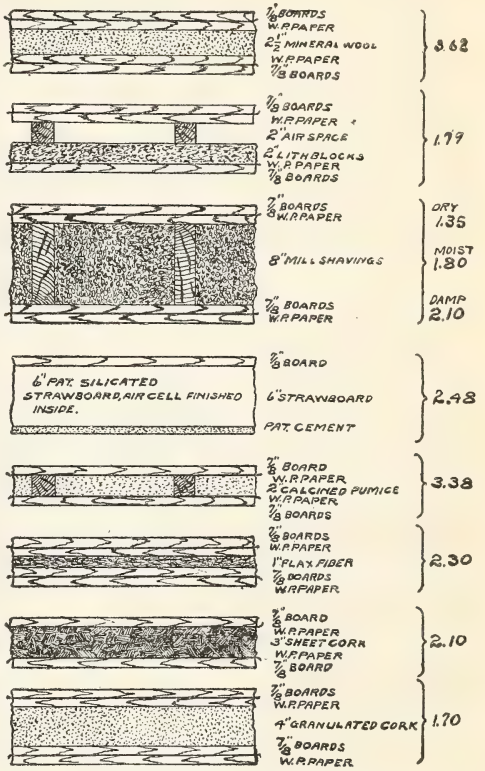



FIG. 24.—B. T. U. transmitted per square foot per 24 hours per degree difference in temperature.

## ESTIMATING THE SIZE OF REFRIGERATING PLANTS.

In determining the size of machinery for any class of work it is necessary to carefully consider the maximum or peak load that it will be called upon to carry. This often results in having to install a great deal larger machine than would be required if the load were uniform. In no class of machinery is this more apparent than in refrigerating apparatus when applied to the dairy industry.

In figure 28 (p. 61) are curves showing the relation between the milk supply and the temperature of the air. These curves are plotted from data obtained from the most important dairying States. The milk-

supply curve is based on the monthly percentage of the average supply. The temperature curve is the average of the mean 24-hour temperatures. Referring to the curve showing the variation in the supply of milk from month to month, it will be noted that there is practically a fixed relation between the temperature of the air and the supply of milk. The average of the milk supply, which is taken as 100 per cent, is available during April and September, while the maximum occurs during June. The highest summer temperature occurs the latter part of July and the first of August, and the maximum amount of work to be done by the refrigerating plant is during July. Therefore the conditions existing at this time should be taken as a basis for determining the size of the refrigerating plant required. If the capacity of the refrigerating plant is sufficient to handle the maximum load running eight hours a day, it will handle the average load running four hours a day. The time of running the machine will decrease from a maximum of eight hours during July until it can be shut down entirely in the Northern States during December, January, and February. In the South it will be necessary to operate the refrigerating plant to some extent during the entire year. The curve marked "compressor curve" shows the approximate daily hours the compressor will have to be operated to produce sufficient refrigeration to take care of the milk during the different months of the year. This curve, however, is based on the milk supply and weather conditions existing in the Northern States, where the dairying industry is principally located at the present time. In the Southern States the daily hours of operation will have to be increased. However, the flush period is not so marked as in the North, as the seasons are longer; consequently the refrigerating load is more uniform and the peak load is not so great.

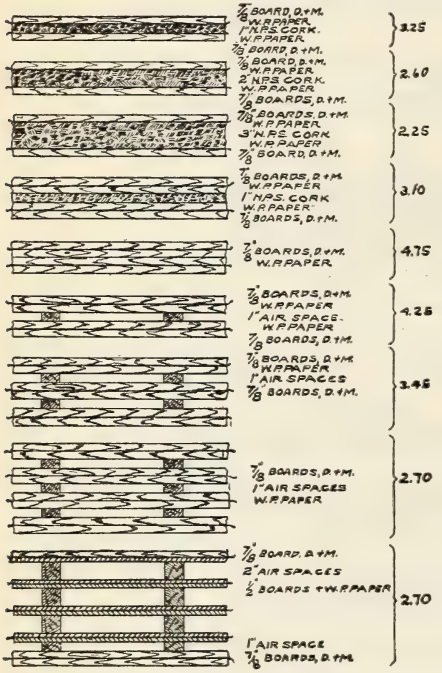



FIG. 25.—B. T. U. transmitted per square foot per 24 hours per degree difference in temperature.

A simple and fairly accurate estimate on the size of refrigerating machine required to do the work of a given amount of ice may be made as follows:

Suppose the ice required to cool a certain size box during the hottest weather is 500 pounds per 24 hours. The refrigeration accomplished by this amount of ice melting is $500 \times 144 = 72{,}000$ B. T. U. Assuming that the conditions existing in the plant will justify the operation of the machine eight hours per day, then the capacity of the machine must be sufficient to extract 72,000 B. T. U. in eight hours, or in one-third of the time that it takes to melt the ice. Therefore the capacity of the refrigerating machine must be $\frac{72{,}000 \times 3}{288{,}000} = 0.75$ ton. Usually lower temperatures than can be maintained by the use of ice are desired, consequently a 1-ton machine, although slightly larger than the requirements, should be installed.

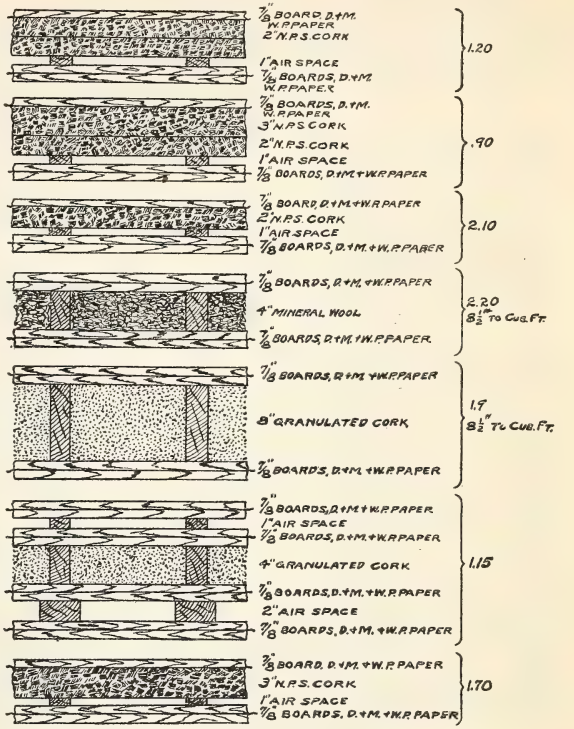



FIG. 26.—B. T. U. transmitted per square foot per 24 hours per degree difference in temperature.

In figure 29 (p. 62) are given the maximum and average temperatures for the different States.

## APPROXIMATE COST OF PRODUCING MECHANICAL REFRIGERATION IN SMALL PLANTS.

The cost of producing a ton of refrigeration mechanically depends upon so many variables, especially in small plants, that it is impossible to give more than approximate costs. The average plant used in creameries and diaries is operated about eight hours daily during the summer months when the work required of the refrigeration machinery is at its maximum. Then the total time of operation diminishes until the machine is shut down entirely or run very little during the winter months.

In most small creameries the engine is ordinarily run for only two or three hours while the churning, working the butter, and pasteurizing is being done. The balance of the day the fire in the boiler is banked and only 10 to 15 pounds' pressure is kept on the boiler. If, in order to operate a refrigerating plant, it is necessary to keep a greater pressure on the boiler and to operate an engine which is a great deal larger than is required for the compressor, the cost per ton of refrigeration will, of course, be greatly in excess of what it would be if the engine was of suitable size for operating the compressor only. Again, the refrigerating machines are often operated intermittently, thereby increasing the cost per ton of refrigeration above what it would be if run continuously. In view of the above, it is impractical to arrive very closely at the actual cost per ton of refrigeration when the compressor is operated by a steam engine which is also used for driving other machinery.

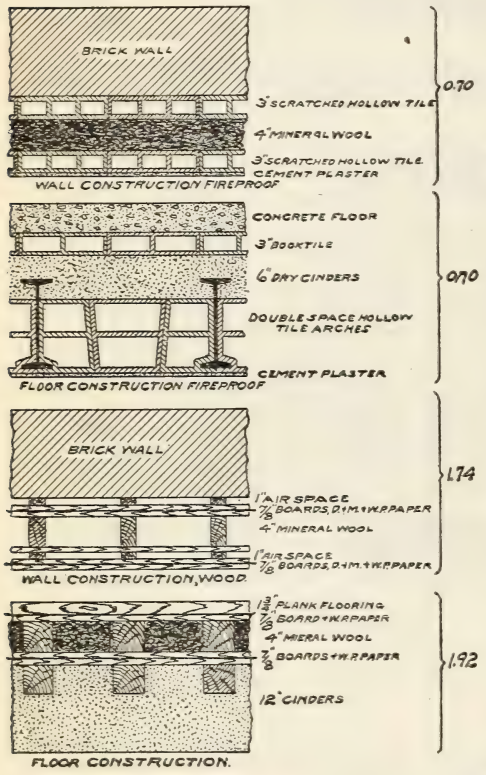



FIG. 27.—B. T. U. transmitted per square foot per 24 hours per degree difference in temperature.

The curves in figure 30 (p. 63), showing the approximate cost of producing refrigeration in creameries with belted, steam-driven equip ment, has been averaged from reports on a large number of creameries, and in view of the fact that the engines were used for purposes other than driving the refrigerating machines, it should be borne in mind that the results are only approximate and should not be considered as positive. The cooling water supplied to the condenser and the wages of an attendant have not been taken into consideration in averaging the cost of producing the refrigeration. The water in most cases costs little or nothing, and it can be used for feeding the boiler, washing utensils, and for other purposes after it has passed through the condenser, as it is only raised a few degrees in temperature. In operating small-machines of the size commonly used in milk plants,

creameries, and dairies, it is unnecessary to employ a regular attendant, as some persons regularly employed in other work on the premises can find time to start and stop the machine and to keep it oiled.

The curve marked "Total cost per ton of refrigeration" has been calculated from the estimated cost of the plant, repairs, depreciation, and miscellaneous items, such as oil, waste, packing, etc. The interest on the money invested is figured at 6 per cent and the repairs and depreciation at 10 per cent.

While the above curves representing the cost of producing refrigeration in the smaller-sized creameries are believed to represent a fair average, it is also believed that the cost can be materially lessened if more attention is paid to the economic operation of the compressor. In a great many instances the engine drove long lines of shafting that were not in the best of condition and a number of idle pulleys in addition to the refrigerating machine.

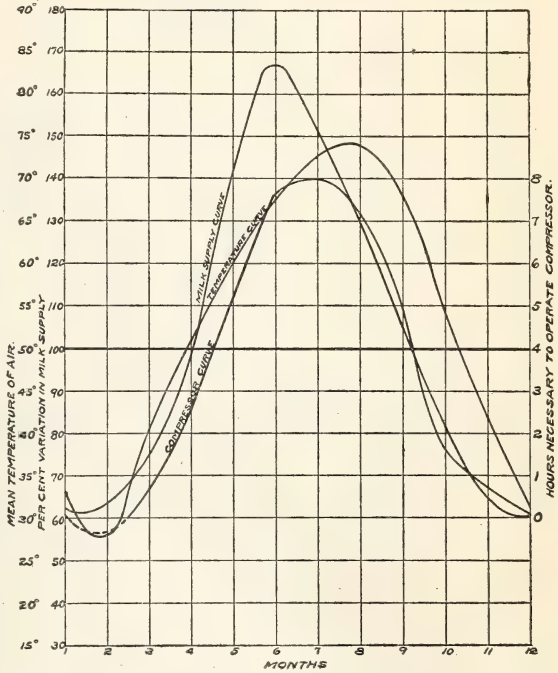



FIG. 28.—Curves showing the relation between the milk supply and the temperature of the air, averaged from the most important dairying States, and the hours necessary to operate the compressor based on the maximum amount of work being done in eight hours.

In many instances where electricity is available motors may be installed at an advantage for operating the refrigerating machine as well as other apparatus. Motors of comparatively slow-speed type can be readily connected by belt to the compressor. With the present price of electric power the cost of operating small units with electricity is slightly greater than when operated by steam power, provided the steam plant is run at or about normal load. But when the engine and boiler are operated at only a fraction of their capacity they become very inefficient and the cost of power is greatly increased. In view of the fact that with electricity the consumption of power starts and stops with the opening and closing of the switch it is often more economical to install electric motors for operating small refrig-

erating machines, even though the creamery is already equipped with a steam engine. This will depend, however, on the arrangement and efficiency of the steam plant and on the cost of electric power and must be determined in each individual case by those on the premises. The cost of power per ton of refrigeration as averaged from steam-driven plants in operation will compare with electric drive at about 3 cents per kilowatt-hour.

There are other advantages in employing electric drive over steam, the value of which can not be estimated in dollars and cents, viz, cleanliness, less space required, and that the power required can be determined accurately at any time.

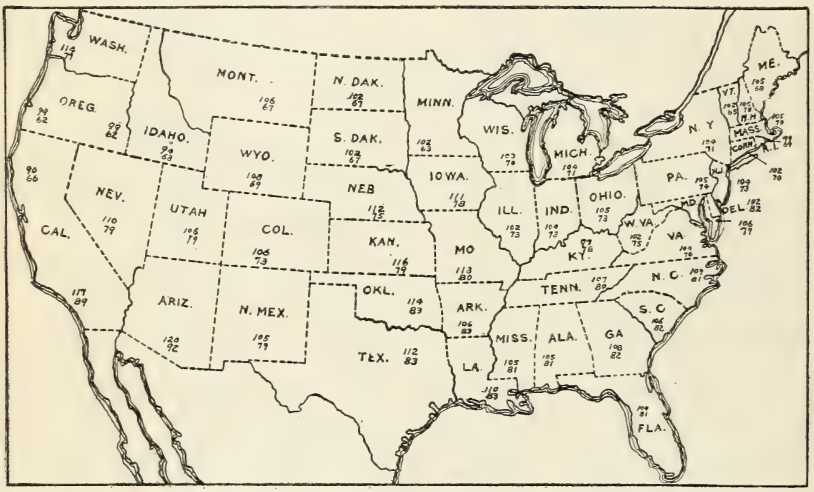



FIG. 29.—Maximum and average summer temperatures in different States.

Cleanliness in milk plants, creameries, and dairies is of special advantage, and with electrical drive practically all the dirt arising from smoke, coal dust, and ashes is eliminated.

It is possible to install electric motors in out-of-the-way places where engines could not be located. This feature makes it practical to locate the refrigerating machine close to the cooling rooms, thereby eliminating long leads of refrigerating piping located outside the rooms to be cooled.

The fact that the power required to operate the compressor can be determined accurately at any time is of great importance. This feature, however, may not seem of very great value at first thought, but it has been proved in many instances to produce higher economy. That the cost of production can be determined accurately is due to the fact that the cost of power is given in each monthly bill or, for that matter, can be calculated each day from the meter readings. With exact figures at his command the operator is able to detect

leaks occurring in production due either to careless operation or to deterioration of the apparatus and is able to judge of the exact value of every movement in the process.

**REQUIREMENTS OF REFRIGERATING PLANTS FOR DAIRY PURPOSES.**

A refrigerating plant suitable for use in milk plants, creameries, and dairies should comply with the following requirements:

(1) It should be reasonable in cost.
(2) Economical to operate.
(3) Reasonably sure against breakdown.
(4) Should produce cool and dry air in storage room.
(5) Should produce lower temperatures than ice.

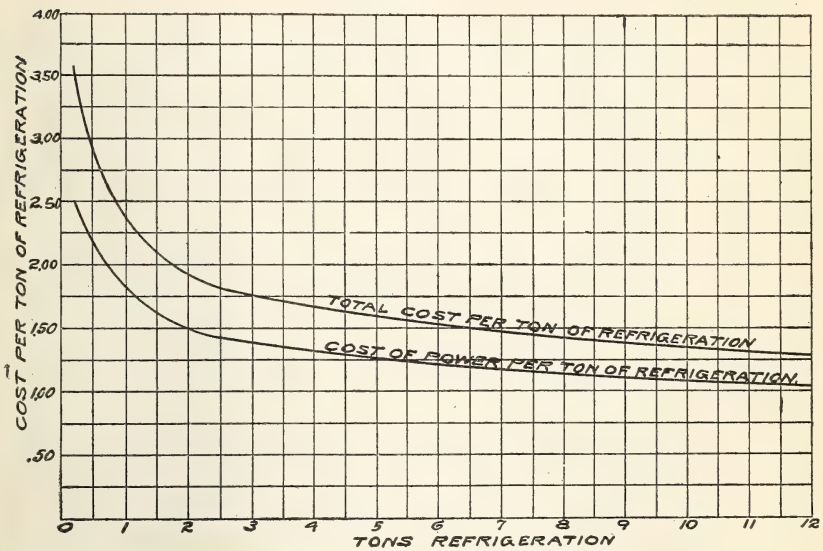



FIG. 30.—Approximate cost of producing refrigeration in the average creamery with belt-driven compressors.

(6) Should give perfect control of temperatures.

(7) Should be simple in construction and operation as to require little attention and be successfully operated by any careful person without any special mechanical or engineering skill.

(8) Should occupy little space.

The initial cost of a refrigerating plant should of course be as small as possible consistent with high-grade apparatus. It is believed that no class of machinery depends more for satisfactory and economical operation on the original design, material of construction, and workmanship than refrigerating machinery. An inferior grade of refrigerating apparatus is an expensive investment at any price and should never be installed. With high-grade machin-

ery and properly arranged and proportioned accessories the cost of repairs and operation is reduced to a minimum.

In the summer months the refrigerating plant is often required to operate continuously in order to handle the increased amount of milk during the flush season, and, furthermore, there is a greater amount of refrigeration required on account of the higher summer temperature. A breakdown at this time would result in the probable loss of the stored products; besides, the daily supply of milk and cream which arrives in the plant at a temperature that will cause the rapid development of bacteria if held even for a short period. During the summer months the temperature of the condensing water will be higher, and consequently a greater quantity will be required for satisfactory operation.

With properly proportioned pipe coils, brine tanks or congealing tanks, and good air circulation within the cold-storage room, cool and dry air will be obtained and a lower temperature and purer atmosphere than is possible with ice. The temperature obtained in the average refrigerator cooled with ice is seldom below 45° or 40° F., and the air always contains more moisture than it should for the best results.

When employing a properly designed mechanical refrigerating plant the temperatures are under perfect control of the operator, regardless of weather conditions; consequently the result is a higher grade and more uniform product. It is absolutely necessary in manufacturing the highest grade dairy products to be able to control the temperatures at will.

As the refrigerating plant is generally operated by persons unskilled in the management of machinery of this type, it should be as simple as possible in its construction and operation, especially in the smaller plants. In the larger plants, however, where an experienced attendant is employed, the equipment may be more elaborate. The apparatus should be designed to occupy as small a space as possible consistent with strength and efficiency, and as it is to be operated by unskilled persons, nothing but the very best material and workmanship should be used in its construction.

In order to keep the size of the refrigerating plant as small as possible, it is advisable to provide storage tanks of ample capacity. The brine should be cooled and a large quantity held for quick action when needed, as when a supply of warm milk is received into the plant and it is necessary that it should be cooled in the shortest possible time. And, further, the cold brine in the storage room can be depended upon to hold the temperatures in case of a temporary shutdown of the refrigerating machine.

In view of the fact that the quantity of milk or cream is liable to vary greatly from day to day, depending upon the supply from the

farms and upon the amount sold, it is necessary to have a considerable margin of safety in the capacity of the brine-storage tank.

The application of refrigeration for dairy purposes depends upon so many variables that it is practically impossible to treat the subject other than in a very general way. Each particular case demands special study in order to obtain the best results, as there are many methods of application according to the character of the business and its particular phases. Generally speaking, however, the brine-storage or congealing-tank system seems to be the one best adapted for most plants, but the medium surrounding the evaporating coils may be either a brine solution of sufficient strength not to freeze at the ordinary working temperature, or it may be confined air, or it may be milk brought in direct contact with the cooling surface of pipes in which the refrigerant is evaporated. In many instances it may be advisable to employ a combination of the different methods in order to obtain the most satisfactory and efficient arrangement.

As there are many methods of application of refrigeration to milk and milk products, we will endeavor to differentiate as far as practicable between the various applications and discuss in a general way what seems to be the one best suited for the purpose, and for this reason the following classifications are made:

(1) Cooling milk on the farm.
(2) Maintaining temperatures during transportation.
(3) Receiving stations.
(4) Cooling milk in bottling plants: (*a*) pasteurizing plants; (*b*) raw-milk plants.
(5) Refrigeration in creameries, general.
(6) Local creameries.
(7) Centralized creameries.
(8) Auxiliary creameries.
(9) Cream-buying stations.
(10) Market cream plants.

## COOLING MILK ON THE FARM.

As the influence of both time and temperature combine to hasten the development of bacteria in milk, it is obvious that it should be cooled just as soon as possible after being drawn from the cow. As has been previously pointed out, the cooling of fresh milk retards the development of the bacteria, which produces fermentation in milk, thereby in turn destroying the milk by causing it to sour. The indications are that at 32° F. the development of bacteria is not only retarded, but there is apparently an actual decrease in their number when held at this temperature. The bacteria referred to, however, are those found in milk, even though produced under favor-

able hygienic conditions, and not to pathogenic (that is, disease-producing) bacteria. It is impracticable to reduce the temperature of milk much below 50° F. in summer without employing a refrigerating machine or ice, and as the former is too expensive for the ordinary farmer, we are limited to the use of ice or well water. Where ice is plentiful and may be had at a nominal cost it is an easy matter to reduce the temperature to, say, 40° F., and by referring to Tables IV, V, and VI under "Influence of temperature and time on the development of bacteria in milk" it will be noted that the multiplication of bacteria at this temperature is very small.

In those locations where natural ice is available it is comparatively an easy matter to cool milk or cream on the farm before carrying it to the receiving station or creamery. This may be done by running the milk or cream over some form of cooler in which cracked ice or a mixture of ice and salt is placed, or through which cold water is circulated.

Where the milk or cream is placed in cans and set in cool water, or even in a tank filled with ice and water, the cooling goes on very slowly, especially if the cans are large. The outside portion, however, may be cooled in a comparatively short time, but unless it is stirred repeatedly it will take considerable time before the interior is cooled down to a point where the development of bacteria is retarded to such an extent that the milk or cream may be safely carried to the receiving station or creamery, as the case may be. It is often the case that a can of milk is set into a cooling vat in which the cooling medium is lower in level than the milk in the can, in which case the milk in the lower part of the can may be cooled down to approximately the temperature of the cooling medium, while that above the level will remain at the higher temperature of the atmosphere; consequently, when the milk is stirred the whole will turn sour and spoil. The cold milk, being heavier than the warm, will naturally remain at the bottom of the can, while the warmer and therefore lighter portion will remain at the top, and practically no circulation will take place and the transfer of heat by conduction in this case is very slow.

If proper care is exercised, however, milk and cream may be cooled down to a temperature sufficiently low to get to the receiving station or central creamery in good condition by running spring or well water through the cooler. In the winter months the lower atmospheric temperatures assist in the cooling, but in the hot summer months the higher temperatures of the atmosphere retard the cooling; consequently, during the hot weather the milk or cream should be run over the cooler very slowly, and if its temperature is not sufficiently lowered it should be run over the second time. In this

way it is possible to get the temperature down to within 2° or 4° of the cooling medium.

As the development of bacteria begins as soon as the milk is drawn from the cow, it is of the utmost importance that the cooling be done as quickly as possible after milking, in order to keep the initial number of organisms down to a minimum. The rapidity at which the development of bacteria goes on in milk at a given temperature depends, of course, on the initial count, hence the importance of keeping the initial count as low as possible.

Tests were made to determine the time required to cool milk by placing a 10-gallon can in a box and running cooling water around the can, as shown in figure 31 (p. 68). The average temperature of the water was 62.6° F. and the flow of water was regulated so that there was practically no difference between the inlet and outlet water. Thermometers were placed in the can, as shown in the attached sketch, and readings were taken every 15 minutes until the temperature of the milk was approximately that of the cooling water. The results of these readings are plotted in the form of curves, which are numbered from 1 to 7, inclusive. Curve No. 8 is plotted from thermometer readings taken in the milk at top of can and shows that that part of the milk above the water level remains from 5° to 6° warmer than the portion below the water level; consequently, bacteria will develop at a higher rate in that portion of the milk above the water level and when mixed will hasten the souring of the milk, both by raising the temperature of the whole and by the increased number of bacteria contained in the warmer portion.

The curve showing the comparatively rapid decrease in temperature when the milk was thoroughly stirred at intervals of 15 minutes demonstrates the advantage of agitating the milk while cooling.

The time taken to cool the milk in either case, however, is too great for good results, and the tests serve best to demonstrate the necessity of employing some efficient form of milk cooler suitable for farm use.

Figure 32 (p. 69) shows the method of cooling milk employed on the United States experimental dairy farm located at Beltsville, Md. The equipment consists of a one-fifth ton refrigerating machine operated by a one-half horsepower motor, a small rotary circulating pump driven from the shaft of the refrigerating machine, and a corrugated milk cooler. Water, instead of brine, is used for circulating through the cooler as the night's milk is cooled, placed in cans, and set into the tank until the next morning; if brine were used it would corrode the cans. The tank holds about 120 gallons of water, which is cooled down to approximately 35° F. and held at this temperature until time for cooling the milk, when it is pumped through

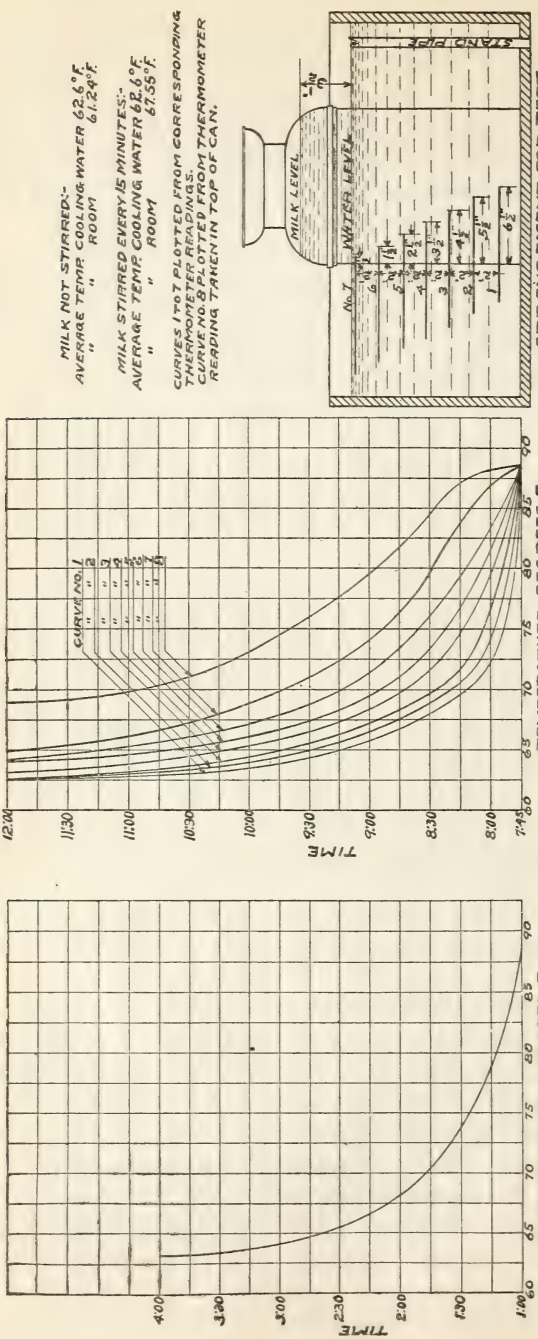



FIG. 31.—Cooling milk with running water.

the cooler by the small rotary pump. The water is allowed to pour back into the tank, consequently the temperature of the volume of water gradually rises. During the warmest weather it was necessary to run the refrigerating machine from 8 to 10 hours a day in order to cool the water down to 35° F. and hold it at this temperature until used. The volume of milk handled was that from 15 cows and it was cooled entirely by the refrigerating water from a temperature of about 98° to 35° F. Had well water been used in one section of the cooler at least half of the refrigerating duty would have been taken off the machine and the time of operating the machine would have been reduced one half, or, for the same number of hours of operation the

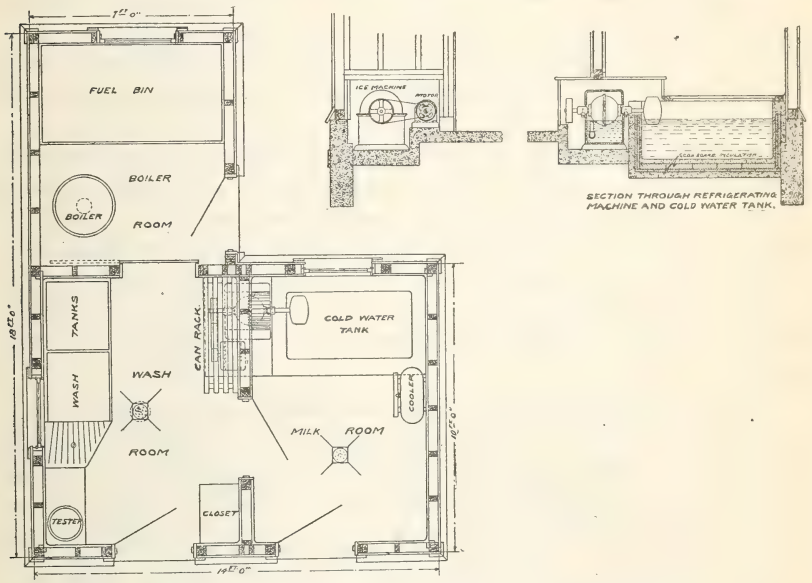



FIG. 32.—20-cow farm milk house equipped with refrigerating machine.

machine would have taken care of the milk of double the number of cows.

The cost of electric current at the experimental farm is 6 cents per kilowatt-hour, and as the input to the motor is about 0.55 horsepower, the cost of power for operating the machine is 2½ cents per hour, or 20 cents for an 8-hour day. The amount of cooling water required is about 25 gallons an hour.

## MAINTAINING LOW TEMPERATURES DURING TRANSPORTATION.

A great deal of the milk consumed in the cities at the present time is transported in wagons, or in the ordinary baggage car in use on the steam railroads or on the interurban electric railways, with no provision for holding the milk at low temperatures.

If, however, milk is thoroughly cooled on the farm and placed in large cans properly jacketed it will arrive at the city plant in good condition under ordinary weather conditions providing the time required for transportation is not over four hours. The transfer of heat through milk is principally by convection, and when in large volumes the transfer is very slow unless the milk is agitated.

The time taken in the transportation of milk from one point to another, together with the facilities available for holding it at low temperatures, determine, to a great extent, the initial temperature to which it should be cooled. For short distances, or short preservation of a few hours only, it is believed that a temperature of less than 50° F. should be maintained. Some lactic acid bacteria will multiply even at this temperature and will cause a souring of the milk, but the increase is slow and for a few hours no serious results will occur. At temperatures below 50° F., however, the rate of bacterial growth is materially decreased.

If, on the other hand, milk is to be shipped long distances, the initial temperature must be lower, assuming that no provision is made for maintaining temperatures during transportation. For comparatively long-distance shipments, where the milk is in transit for several hours, it is necessary to cool it down near the freezing point. The point to which milk should be cooled, therefore, depends on the time taken in transportation and must be determined for each particular case.

In order to maintain a low temperature as long as possible, the cans should be well jacketed. The curves in figure 33 (p. 71) show the result of jacketing the cans. The cans were set in an open truck with no covering to shield them from the direct rays of the sun. Long-stemmed thermometers were inserted through holes drilled in the covers of the cans. Thermometer readings were taken every 15 minutes and the results plotted in the form of curves. The milk was hauled a distance of 13 miles through the country and the average air temperature during the trip was 82.65°. It will be noted by referring to the curves that the total rise in temperature of the milk contained in the hair-quilt-jacketed can was 5½°, while that in the can wrapped in wet burlap was about 8½°, and the unjacketed can showed a rise in temperature of 28½°. It is obvious from the curves that it pays to jacket the cans in order to maintain a low temperature during transportation.

There are at the present time two types of refrigerator cars designed especially for the transportation of milk. One is an ordinarily constructed car of the baggage type, in which the milk cans are set and crushed ice packed around them. These cars are only good for comparatively short hauls, as they are poorly insulated or in most cases not insulated at all. The water from the melted ice

is allowed to run out at the doors, or through cracks in the floors. The other type of car is provided with ice bunkers or brine tanks. In these cars the bunkers are located in the ends of the car and have a ratio of ice to loading capacity of about 1 to 11 cubic feet. In some of the more recent designs of milk cars a mixture of salt and

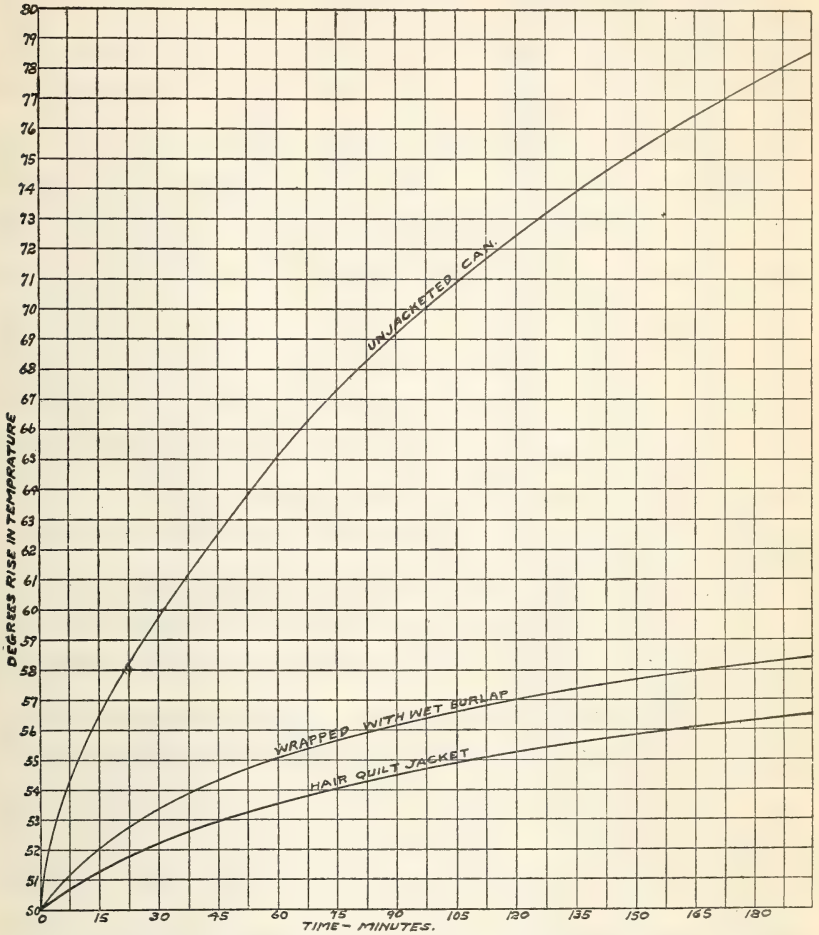



FIG. 33.—Curves showing the relative rise in temperature of milk contained in insulated and uninsulated cans. Average air temperature, 82.65° F.

ice is used to obtain lower temperatures than can be had with ice alone.

One of the latest designs of refrigerator cars for use in transporting milk, employing a mixture of brine and ice, is constructed with two refrigerator compartments, each having a floor capacity of 160 46-quart cans, 13 inches in diameter. The volume of the refrigerating compartment is 1,468 cubic feet. The design of brine

tanks consists of two tanks having a radiating surface of 226 square feet and a volume of 77.25 cubic feet. The screened portion above the tanks has a volume of 9.42 cubic feet, making a total capacity of 86.67 cubic feet, or a total of 3,814 pounds crushed ice, weighing 44 pounds per cubic foot. The ratio of tank radiating surface to loading volume is 1 square foot to 7.48 cubic feet, and the ratio of ice to milk is 2 pounds of ice to 1 gallon of milk. The tanks have a 2-inch free-air space around them and are 15 inches above the floor. They are separated from the storage rooms by a partition open at top and bottom and screened, thus creating a circulation. Any moisture from tanks is carried off from drip pan through drain pipes and traps. The tanks are connected by 1¼-inch pipe, creating to some extent a circulation. This pipe also regulates the brine to a uniform height in both tanks, the height of the pipe above the bottom of the tank being so arranged that a certain amount of brine remains. A riser connection to the pipe forms an overflow.

When refilling the tanks, the valve in the pipe connecting the tanks is opened and all water or brine above the horizontal pipe is drained off. Before refilling the tanks with crushed ice and salt the valve is again closed, causing the warm water to rise to a height equal to the top of the pipe. Any surplus water runs off through overflow pipe and outside trap without egress of air. The valve is manipulated by a rod and universal joints from the roof of the car by removing the plug door.

When it is necessary to clean the tanks, the round plugs at the bottom are unscrewed about one-fourth inch, when they will release the brine, and after it has drained off the plug can be entirely unscrewed and the settlings removed.

In order that the car can be kept in a sanitary condition the floor is covered with galvanized sheet iron, all crevices being soldered, and after each trip or shipment of milk the floors are scrubbed.

It is practicable with this type of car to maintain a temperature of about 35° or 40° F. The milk must be precooled, however, to about this temperature before it is placed in the car, as the refrigerating apparatus is not intended to receive warm milk from the shipper and reduce its temperature to any great extent during transit. A longitudinal section of this car is shown in figure 34 (p. 73).

### COOLING MILK AT RECEIVING STATIONS.

Receiving stations as applied to the milk industry are established for the purpose of receiving, cooling, and handling milk preparatory to shipping. They are located at suitable points along the railroads in dairy sections. The milk is brought to the receiving station by the farmers, usually twice a day during the summer months, early in the

morning and again in the evening. During the winter months the farmers often hold over the evening's milk until the following morning, making only one delivery a day. This is especially true when the farm is located at some distance from the receiving station. During warm weather, however, one delivery a day is impracticable, unless some method is provided on the farm for holding the milk at a temperature sufficiently low to prevent the rapid development of bacteria.

It is necessary that the receiving stations be provided with some means of cold storage in which to store overnight the milk which is received in the evening, and to guard against delays in railroad service, etc.

Most of the receiving stations are owned and operated by the city milk dealers. A few, however, are cooperative or have independent owners. The equipment of these stations varies greatly. The equipment of the smaller stations usually consists of a water tank for ice water and cans, with a small boiler to produce hot water or steam for washing cans and other utensils. The more elaborate establishments are equipped with pasteurizers, bottling machinery, bottle washer, separator, churn, cream vats, and an ice crusher or a refrigerating machine. The latter type of stations are equipped with the view of regulating as far as possible the surplus milk received during the flush season at the station instead of in the city by making butter, condensing, or by separating and shipping only the cream.

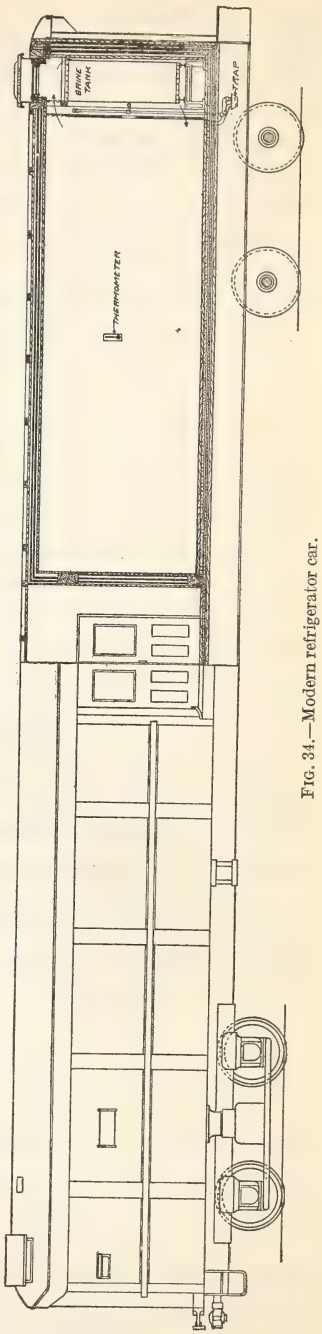



FIG. 34.—Modern refrigerator car.

As soon as the milk is received it is immediately sampled, weighed, and cooled and either bottled or placed in cans ready for placing on board the cars. In the smaller stations the cooling is accomplished by setting the cans into a tank containing ice water, but in the more elaborate establishments

as soon as the milk is received it is weighed and dumped into a vat from which it runs over the cooler to the bottling machine or into cans. Ice water or brine, or often a combination of the two, is circulated through the pipes of the cooler; ice water being run through the upper tubes and brine through the lower. The principal work, therefore, of the receiving station is that of cooling and preparing the milk for shipment. The lower the temperature of the milk, so long as it is kept above the freezing point, the better. With the present state of development of refrigerator cars used in the transportation of milk, they can not be depended upon for lowering the temperature to any great extent during transit; consequently the milk should be thoroughly cooled before loading on the cars. Usually several hours elapse between the time the milk is drawn from the cow until it is loaded on board the cars, which makes it imperative that it be precooled.

The cooling takes placed early in the morning and late in the afternoon, as the milk is received. The time required for cooling seldom exceeds two hours for each period, making the total time employed in cooling about four hours daily. Owing to the short time in which the cooling is done the capacity of the refrigerating apparatus is necessarily large for the amount of work required. It is possible, however, to decrease the capacity of the plant by running the machine a longer time and storing refrigeration in brine, which can be held for quick action when needed.

### COOLING MILK IN BOTTLING PLANTS.

Milk-bottling plants are usually located in cities or towns. The milk is generally shipped in cans direct from the farms or receiving stations, arriving at the bottling plants at a temperature of approximately 60° F. As soon as the milk is received at the city plant it is cooled to a temperature of 45° or 50° F., bottled, and placed in a refrigerated room, and held until the following morning, when it is delivered to the consumer. As the temperature of the room is around 32° F., the milk will come out in the morning at 35° or 40° F.

#### PASTEURIZING PLANTS.

In those plants where the milk is pasteurized previous to cooling the refrigeration required is, of course, considerably greater than in raw-milk plants, where the temperature of the incoming milk is simply reduced to 35° or 40° F. The amount of refrigeration required, however, depends upon the pasteurizing equipment employed.

There are in use at the present time two systems of pasteurization, known as the "holder" and "flash" processes.

The holder process consists in holding the milk or cream for about 30 minutes after it has been heated to the pasteurizing temperature of 140° to 150° F., either in the same apparatus in which the pasteur-

ization takes place or in separate holding tanks arranged for the purpose, after which it flows to the coolers.

In the "flash," or continuous, process the milk flows from the receiving tank to the pasteurizer, where it is heated to a temperature of from 160° to 165° F. in from 30 seconds to a minute, and from thence to the coolers, where it is cooled.

It is obvious, therefore, that there is more refrigeration required for a given amount of milk or cream in the latter, or "flash," than in the former, or "holder," process. It is advisable, however, in both the "flash" and "holder" processes of pasteurization to install between the heater and the cooler a regenerator or heat exchanger, in which the heat is transferred from the hot milk leaving the heater to the cold incoming milk; consequently the milk entering the heater is thus heated while that entering the cooler is partly cooled, the cooler proper reducing the temperature to the point desired.

The milk coming from the regenerator enters the cooler at an average temperature of about 88° F. and is reduced by the water section of the cooler to about 75° F. It then enters the brine section of the cooler, where the temperature of the milk is lowered to an average of 45° F. by low-temperature brine circulated through the coils of the cooler, or in some cases by direct expansion of the refrigerant in the coils. The cooled milk then flows from the cooler to the bottler, where it is bottled and capped, after which it is stored in a refrigerated room and allowed to remain overnight. As the temperature of the storage room is around 32° F. the milk is further reduced to approximately 35° F., at which it goes on the wagons the following morning and is delivered to the consumer.

The work required of the refrigerating machine in a plant of this kind is that necessary to reduce the temperature of the milk from about 75° F., the temperature at which it leaves the water section of the cooler, to, say, 45° F., the temperature at which it leaves the brine section of the cooler, and that necessary for further cooling the milk after it is placed in the cold storage room; also that required to take care of the heat that comes through the insulated walls of the storage room and in lowering the temperature of the glassware and bottle cases. The heat that will come through the walls of the room, of course, depends upon the size of the room, the quantity and quality of the insulation used, and upon the temperature of the outside air.

Assuming a plant handling 1,000 gallons of milk daily, the size of the storage room necessary will be approximately 12 by 13 by 12 feet, with an anteroom, say 6 by 12 feet, giving a total square foot surface of 1,316. If the walls, floor, and ceiling are insulated for a heat transmission of 2 B. T. U. per square foot per 24 hours, for each degree difference between the inside and outside temperatures, and if the average outside temperature is 80° F., then the

refrigeration necessary in 24 hours, when the plant is operated under the foregoing conditions, is:

| | B. T. U. |
|---|---|
| Removing heat coming through walls, floor, and ceiling, $1,316 \times 2\ (80-32)=$ | 126,336 |
| Cooling 1,000 gallons of milk, $1,000 \times 8.6 + .95\ (75-32)=$ | 351,310 |
| | 477,646 |

Additional refrigeration is also required for cooling the glassware and boxes, also a considerable amount is lost due to opening doors and the presence of lights and workmen inside the room. As it is impossible to calculate the refrigeration lost in opening doors, it is customary in practice to allow about 50 per cent additional to cover this. Therefore, the total refrigeration required in 24 hours is, $477,646 \times 1.50 = 716,469$ B. T. U. or $\frac{716,469}{288,000} = 2\frac{1}{2}$ tons. But as the refrigerating machine in a plant of this size is operated only about 8 hours during the 24, the capacity of the machine will have to be three times as large, or $7\frac{1}{2}$ tons.

The operation of pasteurizing, cooling the milk to approximately 45° F., and bottling and storing takes about two hours; consequently it is necessary to have a large volume of cold brine available for this work. The cooling of the brine is accomplished during the forenoon, before the milk arrives, and as the temperature of the brine rises during the cooling process, it is again cooled down in the afternoon and depended upon to hold over temperatures in the storage room during the night.

As a cubic foot of calcium-chlorid brine will absorb about 52 B. T. U. for each degree rise in temperature, and allowing a 15 degree rise, 30 to 45 degrees, each cubic foot will take up $52\ (30-45) = 780$ B. T. U.

The volume of brine necessary for cooling the milk will be $\frac{351,310}{780} =$ 450 cubic feet, providing the refrigerating machine is not operated at the time, but as a $7\frac{1}{2}$-ton machine is capable of extracting $12,000 \times 7.5 = 90,000$ B. T. U. an hour, or during the two hours taken to cool the milk the machine will extract $90,000 \times 2 = 180,000$ B. T. U., consequently the actual cubic feet of brine required is $\frac{351,310 - 180,000}{780}$ $= 219.6$.

Another method of calculating the amount of brine storage required to cool a given amount of milk, based on the capacity of the compressor used for cooling milk, is as follows:

$$T = \frac{(WRm) - (12,000\ CHm)}{60\ Rb}$$

Where $T$ = cubic feet of brine in tank.
$W$ = weighing of milk in pounds.

$Rm$ = temperature range of milk.
$C$ = capacity of compressor used for cooling milk.
$Hm$ = hours required for cooling milk.
$Rb$ = temperature range of brine.

Taking the values in the case under consideration and substituting in the above formula and solving for the number of cubic feet of brine, we have:

$$T = \frac{(8{,}600 \times 43) - (12{,}000 \times 7.5 \times 2)}{60 \times 15} = 211 \text{ cubic feet}$$

During the 16-hour shutdown period the heat that will come through the walls, floor, and ceiling will be $\frac{126{,}336 \times 16}{24} = 84{,}224$ B. T. U., then 219.6 cubic feet of brine will absorb in rising 1 degree $219.6 \times 52 = 11{,}419$ B. T. U., or the temperature of the brine will rise during the 16-hour shutdown period, disregarding the milk in storage, $\frac{84{,}224}{11{,}419} = 7.4$ degrees.

A cubic foot of milk in rising 1 degree will absorb about 61 B. T. U. Therefore the milk in storage, disregarding the brine, would rise only $\frac{84{,}224}{8{,}052} = 10.5$ degrees.

Considering both the brine and milk, a cubic foot will absorb $\frac{132 \times 61 + 219.6 \times 52}{132 + 219.6} = 55.4$ B. T. U., and the rise in temperature will be $\frac{84{,}224}{351.6 \times 55.4} = 4.3$ degrees during the 16-hour shutdown period.

Had the refrigerating machine been of sufficient capacity to have cooled the milk through the required range of temperature in the two hours it took to pasteurize, the size of the machine necessary would have been $\frac{351{,}310 \times 24}{2 \times 288{,}000} = 14.6$ tons. A machine of this size would, therefore, be idle most of the time, and as the initial cost of the larger machine and equipment would be a great deal more than the smaller one, it would be poor economy to install the larger machine.

When either the "flash" or "holder" process of pasteurization is employed, the temperature of the milk is generally first lowered to approximately 75° F. by water from the city mains or from wells; consequently the refrigerating machine has only to lower the temperature of the milk from the temperature at which it leaves the water section of the cooler to the temperature attained in the storage room.

### RAW-MILK PLANTS.

In raw-milk plants it is only necessary to cool the milk from the temperature at which it is received, say 60° F., to a final temperature of approximately 32° F. It is usually pumped directly from the

receiving tank through some form of cooler to the bottler, where it arrives at about 45° F., after which it goes to the storage room. The refrigeration in the storage room is obviously the same as in the pasteurizing plants.

The refrigeration necessary to reduce the temperature of the milk from 60° to 32° F. is $1,000 \times 8.6 \times 0.95 \ (60-32) = 228,760$ B. T. U. The heat coming through the floors, walls, and ceiling is the same as before. Therefore the total amount of refrigeration required in 24 hours, allowing 50 per cent for opening doors, presence of workman, poor workmanship, etc., is $\frac{532,644}{288,000} = 1.85$ tons, or to do the work in eight hours the size of the machine required is $1.85 \times 3 = 5.55$ tons.

The volume of brine required to cool the 1,000 gallons of milk with machine running is $\frac{228,760 - 133,200}{780} = 122.5$ cubic feet. The heat that will come through the walls, floor, and ceiling is $\frac{126,336 \times 16}{24} =$ 84,224 B. T. U. The rise in temperature of brine and milk will be $\frac{84,224}{254.5 \times 56.7} = 5.8°$.

In figure 35 (p. 79) are shown curves of the approximate size and cost of belt-driven refrigerating equipment for various sized milk plants.

## REFRIGERATION IN CREAMERIES.

### GENERAL.

In the application of mechanical refrigeration to creameries the first method employed for cooling cream was to allow it to run over a cream cooler on the way from the separator to the cream vat. This method allowed the cream to be exposed to the air and its contaminating influences; besides, there was no way provided for holding the cream at a constant temperature after it had reached the vat.

The next step was to place the brine piping in an open cream vat. This caused unequal temperatures in the cream and prevented the ripening process from going on at a uniform rate, as that portion of the cream in close proximity to the cooling pipes was chilled down considerably below that at some distance from the pipes. The cream was still exposed to the atmosphere, however. Consequently this method was finally discarded.

Then followed the method of locating the brine or ammonia piping in the water space surrounding the vat, but with this arrangement, as in the foregoing, it was necessary to stir the cream occasionally in order to equalize the temperature of the mass. This method was an improvement, however, as the piping submerged in the jacket water became coated with ice and after the circulation of brine or ammonia had been discontinued the ice would melt and maintain a

fairly low temperature until the cream was ready to churn. This method also had the additional advantage of allowing the brine to be circulated through the coils in the lining of the cream vat after the plant proper had been shut down.

The latest ripening apparatus is arranged for brine circulation through a spiral immersed in the cream and which is rotated at a constant speed, thereby maintaining a constant temperature. By varying the flow of brine any desired temperature may be obtained. The vats are closed and insulated. Consequently contamination

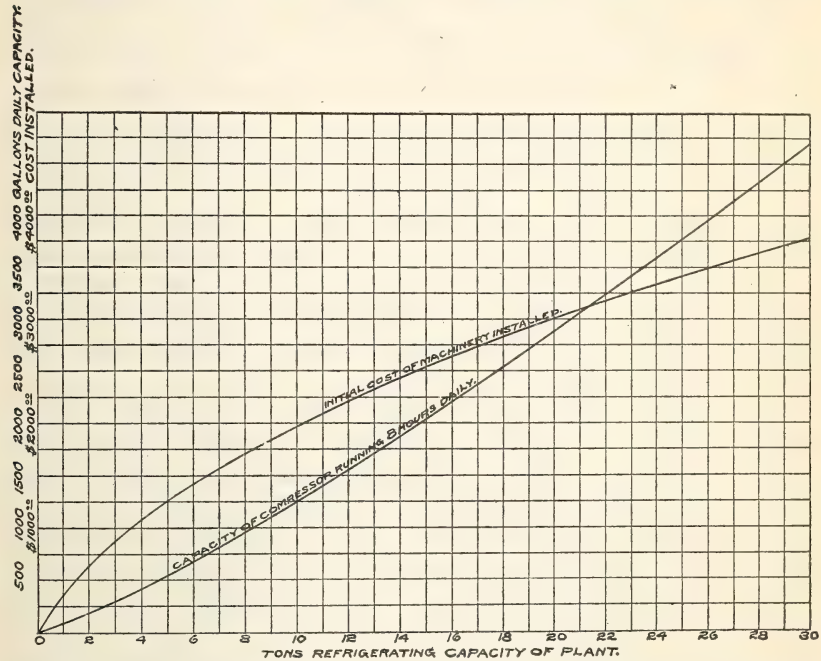

$500 1000 1500 2000 2500 3000 3500 4000 GALLONS DAILY CAPACITY.
$1000 $2000 $3000 $4000 COST INSTALLED.
INITIAL COST OF MACHINERY INSTALLED.
CAPACITY OF COMPRESSOR RUNNING 8 HOURS DAILY.
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
TONS REFRIGERATING CAPACITY OF PLANT.

FIG. 35.—Curves showing the approximate size and cost of belt-driven refrigerating equipment for various size milk plants.

from the surrounding atmosphere and change in the temperature of the cream are prevented.

In no business is temperature control of more importance than in the handling of milk and its products. The perishable nature of milk and the rapidity with which it deteriorates when exposed to ordinary temperatures make thorough cooling facilities a necessity.

In the production of the highest grade of butter it is absolutely necessary that the temperature of the cream during the ripening process be under perfect control in order to check any further fermentation when the proper degree of acidity is reached. As the control of temperatures is very important in the manufacture of high-grade butter, it can best be accomplished by means of mechanical refrigeration, as it enables the buttermaker to control the tempera-

tures of the cream at will, and furthermore mechanical refrigeration does away almost entirely with the mold and slop that must necessarily follow the use of ice. A creamery equipped with a mechanical refrigerating plant can at all times, provided the cream is of good quality, turn out a uniform grade of butter, regardless of weather and temperature changes.

In the modern creamery refrigeration is employed in connection with the processes of pasteurizing, ripening, churning, in the preparation of starters, cooling water for washing butter, in cooling storage for the finished products, and frequently the raw products.

In the pasteurization of cream the same methods are employed as in the pasteurization of milk, viz, the "flash" and "holder" processes. In the "flash" or continuous process of pasteurization the cream is heated to a temperature of 160° F. in about 30 seconds and is then run over some form of cooler where the temperature is lowered to about 65°. From the cooler it is run into the ripening vats, where the proper temperature is maintained for 18 to 20 hours, at which time the cream has ripened sufficiently for churning. As a temperature of 65° is entirely too high for churning, it is lowered by running cold water or brine through the coils in the vat or through the coils of the cooler, should a cooler be used, and the temperature lowered to that necessary for churning.

In practice, however, the ripening temperature of cream varies within wide limits. A ripening temperature that will give good results under certain given conditions would, perhaps, give poor results under different conditions. Consequently the existing conditions will to a great extent govern the ripening temperatures. When the cream is ripened, cooled, and churned on the same day, a higher ripening temperature is of course necessary, while, on the other hand, if the cream is ripened overnight, a comparatively low temperature is employed. The range of ripening temperatures varies from 60° to 80°, but it is believed that between 60° and 70°, with an average of 65°, the best results are obtained, as cream held at these temperatures does not ripen very rapidly. Consequently the desired degree of ripening is approached very slowly and the fermentation may be checked quickly when the desired degree of acidity is reached, thereby reducing to a minimum the chances of getting overripe cream. If, however, the cream is ripened at a high temperature there is a great danger of getting overripe cream.

During the ripening process extreme and rapid changes of temperature in the cream should be avoided as much as possible, as the more uniform the temperatures are kept the better the results.

It is believed that the tendency is toward the "holder" process of pasteurization for cream and also toward pasteurizing directly in the ripening vats. Some types of modern ripening vats are provided with spiral coils or disks through which low-temperature water or

brine is circulated, and the temperature is controlled by regulating the flow. The coils are rotated at a constant speed, thereby insuring even temperature throughout the mass of cream. With an arrangement of this kind the temperature of the cream is raised to 140° and allowed to stand for 30 minutes, when it is cooled quickly to about 65° by circulating cold water through the coils. The cream is allowed to stand at this temperature until it is ripened. The temperature must again be reduced to 52° to 60° before the ripened cream is run into the churn. This latter reduction of temperature of about 10° is accomplished by low-temperature brine or ice water.

The proper churning temperatures also vary, but in summer from 52° to 54° is considered to be an average, while in the winter, the churning temperature rises to about 56° to 60°.

The term "starter" is used to designate a quantity of milk in which lactic acid-forming bacteria have been cultivated until it contains large quantities. This starter is added and seeds the cream with great numbers of these cultivated bacteria, which by their growth cause the acid formation to progress rapidly and in a more definite manner than without the addition of the starter.

In the preparation of the starter a quantity of good skimmed milk is taken and heated to a temperature of 185° to 190° and allowed to stand for 30 minutes, after which it is cooled down to 70° or 80°. To this milk is added the mother starter, which is a pure culture of the desired bacteria, in sufficient quantity to sour the skimmed milk in about the desired time. In order to develop the proper flavor, the perfect control of the temperature of the starter milk is necessary. Where the starter is made every other day it is preserved by holding at a temperature of 50° or below. The amount of starter usually required is one gallon for every 10 or 15 gallons of cream. The cooling of the starter from the pasteurizing temperature, 185° to 190°, is usually done by circulating well water through the jacketed space surrounding the starter can; consequently, mechanical refrigeration is only required to preserve the starter in storage.

An ample supply of pure cold water for working the butter is very desirable. The average temperature of well water, especially in the South, is too high for washing butter; consequently it becomes necessary to cool the water to a temperature sufficiently low for this work. The temperature of the water used in washing the butter depends to a certain extent upon the character of the butter. In summer weather, wash water at a temperature of about 52° to 56° is considered satisfactory, while in winter, the temperature may be as high as 60° to 62°. It may be generally stated that the temperature of wash water should not vary more than from one to three degrees below the temperature of the buttermilk.

The cooling of wash water is done in tanks which should be located at an elevation sufficiently great to command the butter worker and churn. The cooling is done either by direct expansion or brine coils submerged in the tank. The capacity of the tank necessary will vary with the size of creamery, but tanks holding from 100 to 500 gallons are of sufficient capacity for the majority of creameries.

In the medium and smaller sized creameries a cold storage is provided of sufficient capacity to hold at least a week's output of butter, as it is not always convenient to make shipment as soon as made.

The question of the proper temperature at which butter should be stored is an open one. It is at its best, however, when freshly made, and its fine quality will last only a few days if kept at the ordinary summer temperatures. Experiments show that the changes which take place in butter and cause rancidity and other disagreeable flavors diminish as its temperature is reduced. Consequently its quality is determined by the temperature at which it is held rather than the time. The quality and flavor of butter will eventually deteriorate under any storage temperature that has so far been tried. Therefore, the effect of storing at different temperatures is only a matter of degree and not of absolute stoppage of all changes.

It is believed that in the individual creamery where not over a week's output is in storage at one time, that a temperature of 32° F. is satisfactory where mechanical refrigeration is available. Where refrigeration is accomplished by using ice, it is impracticable to get so low a temperature, 50° to 45° F. being about the temperature maintained in the best ice refrigerators.

### LOCAL CREAMERIES.

Local creameries are either cooperative or privately owned, and receive milk or cream, or both, from the immediate vicinity or from their auxiliary creameries located near by. Their equipment usually consists of pasteurizers, coolers, churns, etc., with the necessary motive power apparatus, and often separators for handling the whole milk, which may be delivered direct to the creamery instead of to the auxiliary creamery. Often the local creamery is not supplied by auxiliary creameries but depends on the farmers of the immediate vicinity who deliver the whole milk directly to the creamery, in which case the local creamery does all the separating. Probably the majority of local creameries are supplied with cream separated on the farm and delivered by the patrons to the creamery, or collected by cream haulers.

In a local creamery making, say, 2,000 pounds of butter daily the method of operation is as follows:

In the morning the cream which has been allowed to stand and ripen overnight in the ripening vats is emptied into the churns and the churns started. About three-quarters of an hour is required

to do the actual churning, and about 20 minutes more to work the butter. During this time the cream ripeners are washed.

The arriving cream from the auxiliary creameries or farms is weighed, sampled, and pasteurized. The pasteurizing may be done either in the ripening vats or in a separate pasteurizing machine. When the cream is pasteurized in the ripening vats it is cooled by running cold water through the coils and the jacket surrounding the vat. When a separate machine is used, the cream is run over a cooler on its way to the ripening vats, where it is held at the proper temperature for ripening from 18 to 20 hours. After the churning is finished and the butter packed in tubs or boxes and stored in the refrigerator, the churns and other apparatus are washed as well as the floors of the building. The afternoons are usually given up to office work, making repairs, etc. The machinery is, therefore, operated only about eight hours a day; consequently, the refrigerating machine should be of sufficient capacity to do the work in about eight hours' time.

The size of the room necessary to accommodate a creamery making 2,000 pounds of butter daily is about 10 by 10 by 10 feet, giving 600 square feet surface. Assuming that the walls, floors, and ceiling are insulated for a heat transmission of 2 B. T. U. per square foot per 24 hours for each degree of difference between the inside and outside temperature, then with an average outside temperature of 80° F. the refrigeration necessary is:

| | B. T. U. |
|---|---|
| Removing heat coming through walls, floors, and ceiling, $600\times2(80°-32°)$... | 57,600 |
| Cooling cream, $5,500\times.90(75°-50°)$ | 123,750 |
| Cooling butter, $2,000\times.5494(58°-32°)$ | 28,568 |
| | 209,918 |

In view of the fact that the greater part of the refrigeration is required for cooling the cream, an increase of 25 per cent to compensate for losses of various kinds should be ample. Therefore, the total amount of refrigeration necessary in 24 hours is 262,398 B. T. U. But as the work is to be accomplished in 8 hours, the capacity of the machine necessary is: $\frac{262,398\times3}{288,000}=2.73$ tons, say, 3-ton machine.

The cooling of the cream will take about one hour and the amount of brine necessary, allowing a 10° rise in brine temperature, is $\frac{123,750}{520}=238$ cubic feet, without the aid of the machine at the time. With the machine running during the time the cooling takes place, the cubic feet of brine necessary is $\frac{123,750-36,000}{520}=168$. After the cream is cooled and run into the vats for ripening, the brine is cooled down for holding over the room temperature during the

night. The heat that will come through the walls, floor, and ceiling during the shutdown period is $\frac{57,600 \times 16}{24} = 38,400$ B. T. U. and the temperature of the brine will rise $\frac{38,400}{168 \times 52} = 4.4°$.

The curves in figure 36 show the approximate size and cost of belt-driven refrigerating plants for various sized creameries. The curves are estimates under average conditions of operation and were checked by a large number of such plants now in operation.

In the construction of the cold-storage room great care should be exercised in selecting and installing the insulation. It has been shown under the section on insulation that three-fourths of the work

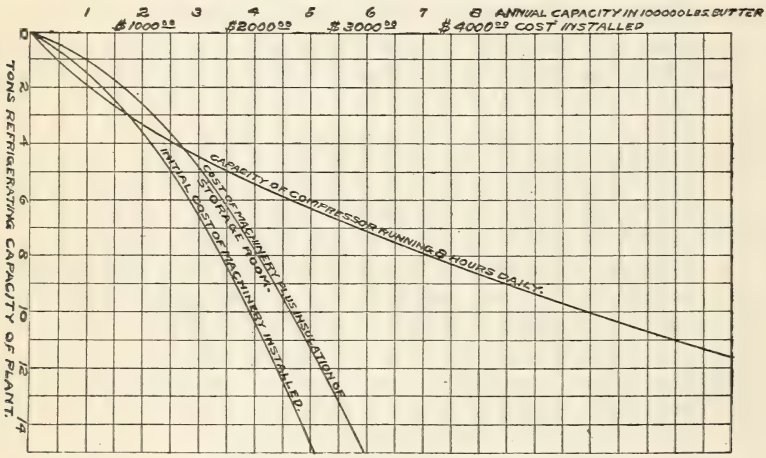



FIG. 36.—Curves showing the approximate size and cost of belt-driven compressors for various size creameries.

of refrigeration required for cold storage is utilized in "pumping out," so to speak, the heat that comes through the walls, floor, and ceiling of the room. In addition to the insulating value of modern insulation, it serves as a protection to the goods in storage in case of fire, due to its slow burning qualities.

It is often advantageous in creamery cold storage to provide extra rooms for the purpose of storing eggs and poultry. They should never, however, be stored in the same compartment with the dairy products, as they will impart a taint to these goods.

### CENTRALIZED CREAMERIES.

Centralized creameries, as the name implies, are established for the purpose of handling and manufacturing into butter the cream received from many outlying stations, or from direct shippers. The outlying stations are usually termed "cream-buying stations" and often located at a distance of 100 miles or more from the main creamery.

The centralized, or main, creamery is usually located on a railroad or, better still, at the intersection of two or more railroads. The cream-buying stations are distributed along the lines of the railroads in the most favorable locations for collecting cream. The collected cream is shipped to the centralized creamery, the time of arrival, of course, depending upon train schedules. In some instances cream arrives at practically all hours, both day and night. As soon as received at the creamery, the cream is sampled, weighed, and pasteurized. After pasteurization the cream is cooled and run into vats where it is held until the following morning, when it is churned. Generally the churning and the working of the butter take place in the forenoon, although in some instances this work is done at any time that happens to be the most convenient.

Usually the cream is ripe when received, and if churning is to be delayed the temperature of the cream is lowered to a point where the development of acid bacteria practically stops, at which temperature it is held until ready to churn.

In case a force is kept on duty continuously, the refrigerating plant may be operated 24 hours a day; hence, the size of the plant is materially reduced from that required if the plant were operated only 8 hours. Generally speaking the methods of operation employed in the centralized creameries are very similar to those of the local creamery, except they are on a more extensive scale and only cream is handled.

### CREAM-BUYING STATIONS.

Cream-buying stations are established for the purpose of supplying the centralized creameries with cream by collecting the cream directly from the farmers and shipping to the main creamery. These stations are located at suitable points along the railroads in close proximity to a large number of farms. The cream is brought to the buying stations by the farmers, where it is received by the agent of the main creamery and held until a sufficient quantity is on hand to justify shipping. Generally no provision is made for cooling the cream at the buying stations.

In figure 37 are given the weights of a gallon of cream containing varying percentages of fat.

### COOLING CREAM IN AUXILIARY CREAMERIES.

The auxiliary creameries, commonly known as skimming stations, are erected for the purpose of furnishing cream to the main creamery without the inconvenience of having to haul the raw milk a long distance. By separating the cream from the milk in the auxiliary creamery and hauling only the cream to the main creamery a great saving in time and labor is effected, as it is necessary to haul only about an average of 13 per cent of the total weight of the whole milk.

The auxiliary creameries are located at suitable points in the country surrounding the main creamery, where they are in close proximity to a number of farms. Where a creamery draws its supply of milk from a large and scattered area, the auxiliary creameries are essential to its economical operation.

The milk is brought to the auxiliary creamery by the farmers early in the morning and it is immediately sampled, weighed, and separated. The skimmed milk is returned to the farmers, who haul it home for feeding to stock, and the cream is run from the separator over a cooler, caught in cans, and carried to the main creamery, where it is ripened and made into butter. In some States the skimmed milk is heated before being delivered to the farmers to a temperature of 180° F. in order to destroy any disease-bearing bacteria that might be transmitted to stock by feeding on the milk.

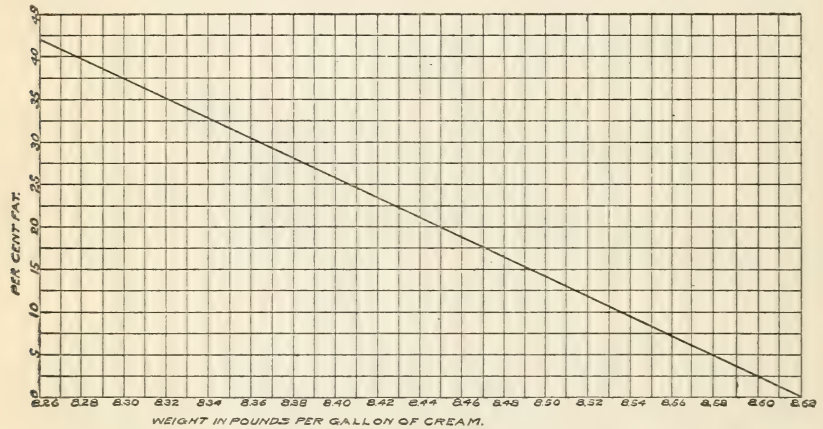



FIG. 37.—Weight of a gallon of cream at 68° F. with varying percentages of fat.

Before separating the whole milk its temperature is raised to 90°. It is then run through the separator, coming out at a slightly lower temperature than that at which it entered. It should be immediately run over some form of cooler and its temperature reduced to an average of about 40°, at which temperature it should be run into insulated cans and carried to the main creamery, where it is ripened and made into butter. It is practicable to reduce the temperature of the cream by the water section of the cooler to about 60° in the Northern States, but in the Southern States a temperature of 70° is about as low as it is practicable to lower the temperature by well water. From the temperature at which the cream leaves the water section of the cooler to a final average temperature of 40° the cooling is done in the more modern creameries by circulating low-temperature brine or water through the coils. In those localities where natural ice is available at a small cost the cooling is generally done by employing a mixture of salt and ice. In the Southern States, however, where natural ice

is not available and the cost of manufactured ice is too great for economical use, mechanical refrigeration is desirable in order to reduce the temperature of the cream to a point where it can safely be carried to the main creamery.

Due to the development of the hand separator, by the use of which the farmer is enabled to separate his milk on the farm, the auxiliary creamery is fast being done away with. This arrangement, however, places the responsibility of properly cooling the cream upon the farmers before it is hauled or shipped to the creamery. What has been said on the subject of cooling milk on the farm is, of course, applicable to the cooling of cream, and as the weight of cream is only about 13 per cent of that of the whole milk, the cooling is a comparatively easy matter.

Where the separating is done at the auxiliary creamery the milk is first heated to about 90° before being run through the separator. The temperature of the cream is first reduced by the well-water section of the cooler to approximately 60°.

Assuming that the auxiliary creamery handles 1,500 pounds of cream daily through the summer months, and the temperature of the cream when received is 60°, and that it is cooled to an average temperature of 40°, the refrigeration necessary to cool the cream is $1{,}500 \times .90(60-40) = 27{,}000$ B. T. U. But there is the loss in cooling brine, radiation, etc., that must be taken into consideration.

Owing to the variation due to poor workmanship, the arrangement of the apparatus, etc., it is impracticable to calculate very closely on the amount of refrigeration that will be lost. Therefore it is customary to allow a certain amount to cover this loss, which usually varies from 25 to 50 per cent. In the case under consideration 25 per cent would be ample. During the summer months the machine would be run about 6 hours per day; therefore the size of machine necessary would be $\frac{27{,}000 \times 1.25 \times 4}{288{,}000} = 0.5$ ton.

A cubic foot of calcium-chlorid brine will absorb about 52 B. T. U. in rising 1° F., and allowing a 10-degree rise in brine, 30 to 40 degrees, each cubic foot will absorb $52(40-30) = 520$ B. T. U. Therefore the volume of brine required for cooling the cream is $\frac{27{,}000}{520} = 52$ cubic feet, providing the machine is not running during the cooling process. But with the machine in operation the volume of brine will be considerably less. A half-ton machine is capable of extracting 6,000 B. T. U. per hour. Consequently as the machine is run during the two hours of cooling it will extract 12,000 B. T. U. and the volume of brine necessary will be $\frac{(27{,}000 \times 1.25) - 12{,}000}{520} = 41.8$ cubic feet.

As the amount of heat that will come through the walls of the brine tank is directly proportional to the exposed outside surface, and as

the cost of insulation also varies in the same proportion, it is obvious that the brine tank should be constructed in the form of a cube which gives the least exposed surface for a given volume of any form of rectangular tank.

The brine tank should be in the form of a cube with 3-foot 8-inch sides, giving a surface of 80 square feet. The tank should be insulated for a heat transmission of not over 2 B. T. U. per square foot, per 24 hours per degree difference between the inside and outside temperature.

### MARKET CREAM PLANT.

The market cream plant, as the name implies, handles only sweet cream for the market. The plant is usually provided with churns in order to make butter from any soured cream that may accumulate, otherwise the equipment consists of that necessary for pasteurizing and cooling.

The method of operating a plant of this kind is essentially the same as that employed in operating a regular local creamery; that is, the plant is located on a railroad where good connections are had with the markets. The milk or cream is received from the producers or auxiliary creameries, usually early in the morning, and is pasteurized and refrigerated immediately. In a market cream plant it is imperative that the work be done quickly and thoroughly in order to get the cream on the market in perfect condition. In this type of plant refrigeration is of the utmost importance, as the safe handling of the cream depends more on the proper cooling than any other one feature of the business.

The amount of refrigeration required in the market cream plant is of course considerably more than that for a creamery handling the same amount of cream for butter making, as the temperature maintained for market cream is considerably lower. In ripening cream for butter making it is seldom that its temperature is allowed to go below 50° F., about 65° F. being the usual ripening temperature. With cream intended for the market, however, a temperature of just above the freezing point is desired. Shipping facilities often require the holding over of one day's supply of cream to the morning of the following day, consequently suitable provision for cold storing must be provided.

What has already been said on the cooling, storing, and shipping of milk is of course applicable to cream.

ADDITIONAL COPIES

OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
10 CENTS PER COPY

▽

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1914

NATIONAL AGRICULTURAL LIBRARY
1022831871